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COLOUR REPRODUCTION IN THE USE OF DIFFERENT SOURCES OF "WHITE" LIGHT

by P. J. BOUMA.

Summary. The requirements which have to be satisfied as regards colour reproduction differ considerably for different practical applications. An investigation is made as to what conditions the spectral distribution and the point in the colour triangle have to meet:
a) In order to obtain a "pleasing and agreeable" reproduction of colour (i.e. suitable for indoor illumination); and
b) To obtain a "correct and natural" colour reproduction (i.e. coinciding with that obtained in daylight).
A method is developed with the aid of Ostwald colour cards for the comparison and estimation of colour reproduction of different light sources. This is followed by a discussion of a series of examples of light sources which simulate daylight.

In a previous article [1]) it has already been shown that the colours which we perceive in surrounding objects are determined to a marked degree by the nature of the light which is incident on these objects. It thus follows that certain types of light are quite unsuitable for some purposes of illumination. Thus sodium lighting cannot be used in living rooms, where a differentiation between colours must be possible and the colours of different objects must appear pleasing and possess more or less their natural hues, requirements which sodium lighting is by no means able to meet. A further example is mercury light which cannot be indiscriminately used in stores where coloured materials are sold, for these colours not only appear different under mercury lighting than in daylight, and a purchase may easily lead to keen disappointment when seen later in daylight, but it may even occur that under mercury lighting two materials will produce exactly the same colour sensation, while appearing entirely different in daylight [2]).

These examples indicate that the problem of providing a satisfactory source of "white" light is rendered increasingly difficult owing to the variety of requirements which have to be met in individual cases. It is obvious that a single source of light cannot be evolved which will give a satisfactory illumination in all circumstances.

For use in living rooms the principal requirement is that the light must be pleasing and not irritating, while in stores and wherever colours have to be differentiated, judged or compared, the reproduction of colours must be as close as possible to their daylight hues. It will be found below that these requirements are in general incompatible.

We shall at the outset discuss the first requirement and consider the question:

What types of light give a pleasing reproduction of colour?

We are dealing here with an essentially practical problem which cannot be disposed with by mere theoretical analysis. To obtain an appropriate answer to our question we would have to exhibit a wide variety of light sources to a large number of observers, asking them to select that giving the most pleasing and agreeable illumination. But it is doubtful whether an investigation on even these comprehensive lines could lead to a satisfactory solution. Selection of the most pleasing light source would be governed, *inter alia*, by the following factors:

1) Philips techn. Rev., **1**, 283, 1936.

2) This state of affairs is reached already when e.g. the reflecting powers of the two substances in the red band differ considerably and are the same for other spectral colours.

1. The question of habit: We have become so accustomed to seeing by daylight (with high intensities) during the day and by electric light (with lower intensities) during the evening, that we are inclined to regard all sources of light markedly different to them as "unnatural".

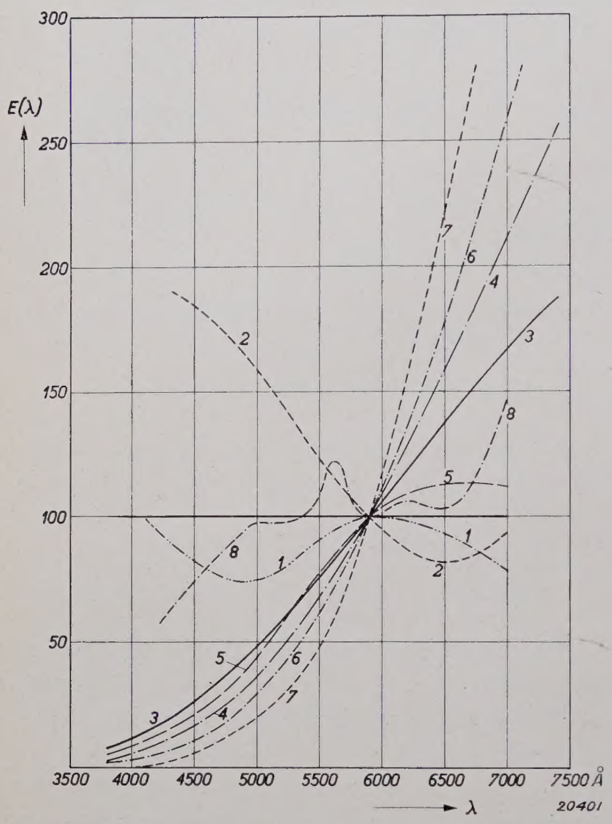


Fig. 1. Spectral distribution of various sources of "white" light. *1)* Daylight, overcast. *2)* The light from a clear blue sky. *3)* Gasfilled incandescent electric lamp. *4)* Vacuum incandescent electric lamp. *5)* Incandescent gas lamp. *6)* Carbon filament electric lamp. *7)* Paraffin lamp. *8)* Daylight lamp. (The intensity at 5900 Å is taken equal to 100).

2. The method of comparison: A source of light may be intrinsically quite pleasing and yet appear unsatisfactory if its suitability is tested at the same time as or immediately after a test on an entirely different type of light.
3. The question of intensity: It is evident that preference will be given to a different type of light at higher intensities than at lower intensities.

As a first step towards the solution of this problem, we shall investigate those sources of light which have hitherto been found suitable and satisfactory in practice.

For a series of light sources, the spectral distribution (the energy E at $\lambda = 5900$ Å being put equal to 100 for all light sources) is shown in *fig. 1*, while in the colour triangle in *fig. 2* the points are marked corresponding to the light emanating from the light source [3]). We have represented the different light sources in both ways here, because the spectral distribution alone does not give us directly an idea of the nature of the colour sensation produced by the light source itself, while on the other hand the colour triangle gives little information how each particular type of light reproduces the surrounding colours. In this respect, there is, for example, little similarity between daylight and a mixture of two complementary spectral colours (yellow and blue). If the mixture has been made in the correct proportions, then the light emanating directly from the two light sources will give the same colour sensation and is therefore represented by the same point in the colour triangle. But the reproduction of colour is entirely different: the second light source makes all objects appear white, grey, blue or yellow (the last-named colours with different degrees of saturation).

The following types of light are represented in the figures:

1) Daylight (results of measurements made at Utrecht with an overcast sky). The composition of the light varies fairly considerably; in fig. 2 a few results are given, while in fig. 1 only one spectral curve is given as an example.

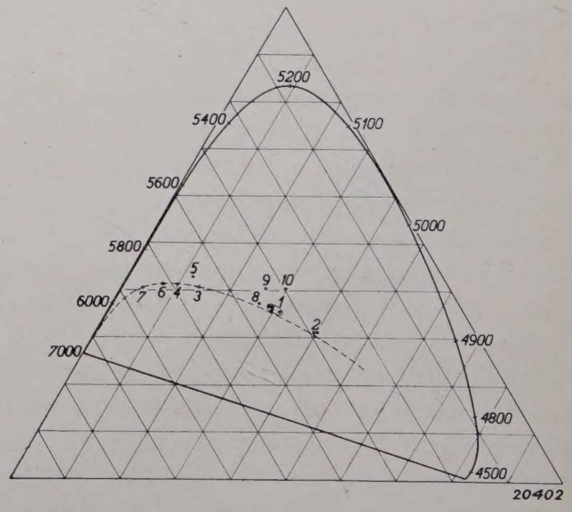


Fig. 2. Colour triangle with spectral colours (——), black bodies (----), the light sources in fig. 1 (Nos. *1* to *8*), high-pressure mercury lamp *(9)* and super-high-pressure mercury lamp *(10)*.

2) The light from a clear blue sky (also from measurements at Utrecht). This type of light is

[3]) Regarding the representation of colours in a triangle see Philips techn. Rev. **1**, 283, 1936. In addition to the various sources of "white" light the spectral colours (——) and the black bodies of various temperatures (----) are also included in the diagram.

obtained in the main when on sunny days we are at any point in the shade. These lights *(1)* and *(2)* at the brightnesses occurring during the day are generally found to be satisfactory.

3) The light from a gasfilled incandescent electric lamp.

4) The light from a vacuum incandescent lamp.

5) Incandescent gas lamp.

Both as regards spectral distribution and the point in the colour triangle, these three light sources differ very considerably from daylight. Yet on the whole they are regarded as satisfactory, and we find them pleasing. The divergence in colour reproduction (compared to that obtained with daylight) only tends to become disturbing when an attempt is made to differentiate colours with these lights. In other respects we are hardly aware of how very different objects appear when seen in these lights than when viewed in daylight.

6) The oldest type of electric lamp: the carbon filament lamp.

7) The paraffin lamp.

These two types of light differ still more from daylight, and have a fairly saturated orange-yellow colour. The paraffin lamp is also accepted as giving an agreeable light, although the divergence in colour reproduction is so pronounced that we are quite well aware of this divergence in everyday life.

8) A socalled daylight lamp, i.e. a gasfilled incandescent electric lamp with a special blue bulb which serves to adapt the light to daylight.

The following general remarks may be added to supplement the above:

In the colour triangle all points for the types of light under consideration lie either on or close to the line for the black body (-----). All have spectral distributions without sharp maxima or minima; daylight *(1)* and *(2)* give very high colour temperatures (4500 to 8000 °K), while those sources used for interior illumination have much lower colour temperatures (1750 to 2850 °K).

Why do we prefer for interior illumination such sources of light which have a much lower colour temperature, i.e. are more yellowish than sunlight?

It might be assumed that we have chosen them just because they are the only sources of light which have been evolved on a commercial scale and that we have gradually grown accustomed to them. But this would not be correct. We can quite readily modify the colour of our light with lamp shades and coloured transparent materials, and the striking observation is then made that the great majority of these materials are y e l l o w, i.e. by shading our electric lamps we are still further reducing the colour temperature. To obtain a pleasing appearance we depart still further from daylight, electric lamps *per se* already marking a divergence therefrom. The conclusion to be drawn is therefore that during the day we are very well satisfied with daylight but . . . at the small intensities which we have in living rooms during the evening, we show a preference for a more yellowish light, i.e. light with the lower colour temperature. Light of equivalent spectral composition to daylight appears cold and lacks cheerfulness at low intensities.

These assertions are confirmed by a wealth of practical experience. During eclipses of the sun our surroundings appear pratically the same as in ordinary daylight, but are illuminated with a much lower intensity. The sensation obtained is by no means cheerful since the colour temperature is too high for this intensity. For the self-same reason daylight lamps used in a living room do not as a rule give a pleasing effect. If on dull days the daylight entering our rooms appears insufficient, supplementing it with electric light produces a depressing result: The combination gives us a spectral distribution to which we are not accustomed under these circumstances; we therefore don't like it.

An important factor in judging the suitability of a particular source of light for indoor illumination is whether colour distortion may suggest to us disagreeable things, for instance whether the face looks unhealthy and food assumes unnatural colours, etc. One of the factors which lead us to lower colour temperatures is certainly that with such light sources the skin appears to have a fresher and healthier colour.

In general, we are inclined to make up for the lack of illumination provided by artificial light as compared with daylight by the use of "warmer" colours (i.e. usually those containing more red).

The most acceptable sources of light for indoor illumination are therefore those whose spectral distribution closely resembles that of a black body with a low colour temperature (2800 °K or less). Yet to provide a comprehensive answer to the question posed above extensive investigations are still necessary.

We now come to the second question:

[4]) The colour temperature of a light source is the temperature which a black body ought to have to give the same relative spectral distribution.

What light sources offer a "correct" colour reproduction?

In other words: What requirements must a light source satisfy in order to reproduce colours in the same way as in daylight?

As we have already seen above, a consideration of the points in the colour triangle here again cannot provide us with an answer. We must moreover also take the spectral distribution into consideration. Colour reproduction will only be absolutely identical with that in daylight, when the spectral composition is fully equivalent to that of daylight.

But just as the eye experiences difficulty in differentiating between small differences in brightness [5]), so also is it unable to distinguish very slight differences in colour. There is in fact a certain minimum difference — which for the sake of brevity we shall term a step — which is necessary before differentiation becomes possible on comparing two colours.

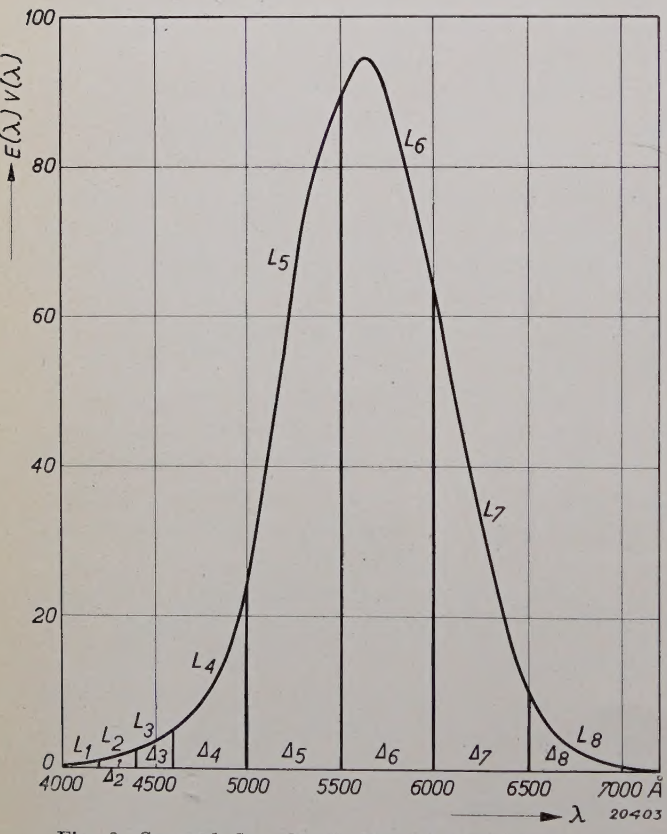


Fig. 3. Spectral flux distribution of daylight (energy distribution times ocular sensitivity curve) with subdivision into sections Δ_1, Δ_2, . . . each giving a total luminous flux of L_1, L_2, . . . respectively.

It thus follows that the relative spectral distribution of the lamp which is to simulate daylight need not be absolutely equivalent to that of daylight. Not only can the relative proportions of a specific wave length to the total intensity in the two spectra be slightly different, but the light with a particular wave length can also be replaced by that of a neighbouring wave length. Hence it is even possible to simulate daylight with a source of light which has a line spectrum, provided the lines (if necessary supplemented by a continuous band) sufficiently fill the whole of the visible region. It is found here also that mercury light (see also fig. 2; *9* applied to a high-pressure mercure lamp, and *10* to a super-high-pressure variety) even if suficient red light is mixed with it, is again not suitable for simulating daylight: The spectrum contains gaps of still too great an extent, particularly in the blue-green and the blue.

How can we arrive at a quantitative standard which the spectral distribution must satisfy? In *fig. 3* the spectral flux distribution of daylight is shown [6]). The wave-length band is divided into sections Δ_1, Δ_2, . . . , each section making a flux contribution of L_1, L_2, . . . (proportional to the area under the curve of each sectional component). When using the same subdivision for another source of light we get corresponding values L_1', L_2', . . . If these sections have been taken sufficiently small, the substitutional light source will simulate daylight with sufficient accuracy, when the components L_1', L_2' . . . differ by less than p_1, p_2, . . . per cent from the values L_1, L_2, . . .

Investigations were made to determine to what extent the colour sensation due to an arbitrary pigment could fluctuate when illuminated by different light sources with components L_1, L_2, L_3 . . . It was found that the following subdivision of the wave-length band into eight sections was sufficient: 4000-4200-4400-4600-5000-5500-6000-6500-7000 Ångstrom units. It was desirable — as adopted here — to make a finer subdivision in the blue than in the rest of the band. The method of subdivision employed was found more satisfactory than a subdivision into ten equal components.

With this subdivision how large are the permissible tolerances p_1, p_2, p_3, . . . i.e. how far can the flux components of the lamp and daylight differ in each of the selected divisions without the quality of colour reproduction being adversely affected? To investigate this question we shall assume that colour reproduction may be regarded as satisfactory when an arbitrary object, illuminated partly with daylight and partly from another source

[5]) See Philips techn. Rev. 1, 102, 1936.

[6]) This curve is obtained by multiplying the spectral energy distribution E (λ) (fig. 1, curve *1*) by the relative ocular sensitivity V (λ).

of light, exhibits a colour difference not exceeding 4 steps. On this basis, it can be calculated that the tolerances in the eight wave-length sub-bands chosen are roughly the same (confirming that the method of resolution was correct); they were all 20 to 25 per cent.

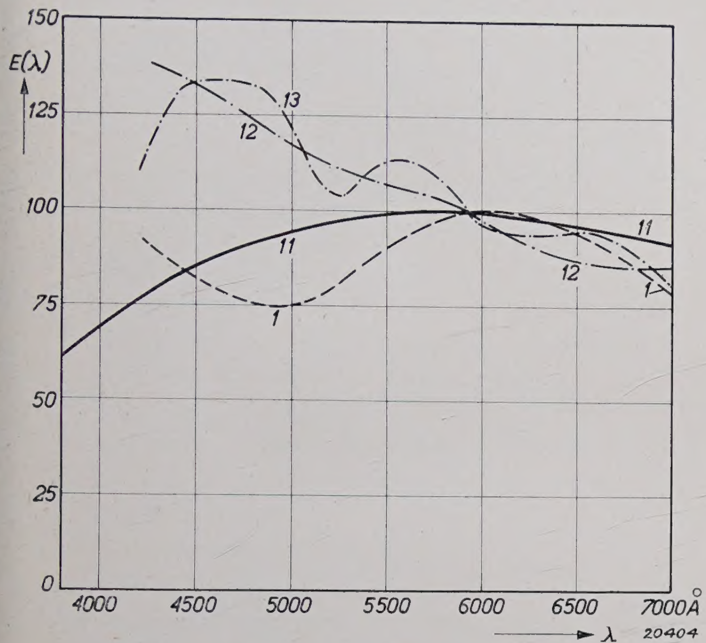


Fig. 4. Spectral distribution of various sources of "white light.
1) Daylight (overcast),
11) Black body (5000 °K.),
12) Mean of curves *1* and *2* in fig. 1,
13) Standard light source C (I.C.I., 1931).
(The energy at 5900 Å is taken as 100).

This conclusion will be discussed on the basis of a number of examples.

It is seen from fig. 1 that the energy distributions in the gas-filled incandescent lamp (*3*) and the vacuum lamp *(4)* differ by more than 25 per cent only in the blue. These two light sources thus differ slightly too much from each other to permit us to regard them as giving an identical colour reproduction. Also the difference between the daylight lamp *(8)* and daylight *(1)* is still too great.

Fig. 4 gives the curve *1* for the daylight measurements reproduced in fig. 1 and also the curve *11* for the radiation of a black body at 5000 °K. Within the tolerances stated above the two curves are in satisfactory agreement. In regard to colour reproduction it is thus permissible to replace the light obtained with a clouded sky by that afforded by a black body at 5000°K.

Curves *12* and *13* in fig. 4 also coincide within the limits laid down. These represent the mean of the curves for an overcast and a clear sky (curves *1* and *2* of fig. 1) and the standard light source (C) used as specified by the International Commission on Illumination (1931), in order to determine the appearance of colours under average daylight illumination.

Finally, it may be concluded from fig. 1 that the paraffin lamp *(7)*, the incandescent electric lamp *(3)* and daylight *(1)* differ far too much from each other to ensure equivalent colour reproduction. Colour reproduction with gaslight *(5)* is practically the same as with electric light *(3)* (the differences being rather large only in the red).

How can we compare the colour reproduction of two light sources?

Up to the present we have studied what conditions the spectral distribution of a light source must satisfy in order that its colour reproduction shall satisfactorily approximate to that of another light source. To ascertain under practical conditions how far the agreement between the two light sources extends, the best way lies in observing a large number of coloured objects under the illumination of each of the sources in question.

A series of objects most suitable for this purpose are the colour cards of the well-known Ostwald

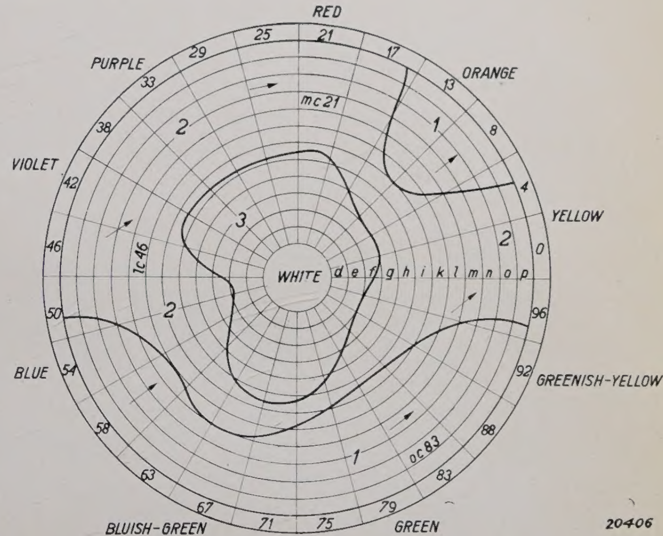


Fig. 5. Comparison of colour reproduction between a daylight lamp and daylight.
3) Region of unsatisfactory agreement,
2) Region of moderate agreement,
1) Region of good agreement, and
0) Region of full agreement.
The components represent the colour cards of the Ostwald colour atlas. The saturated colours lie at the outside and the less saturated colours at the middle.

colour atlas. This collection contains about 2000 coloured cards, each of which is denoted by two letters and a number (e.g. *oc* 83). The first letter denotes the saturation of the colour, the second the coefficient of total reflection, and the number

the dominant wave-length [7]). Let us select from this series the groups *dc*, *ec*, *fc* . . . *pc* and of these the numbers *0*, *4*, *8*, . . . *96*, arranging the cards in concentric circles as shown in *fig. 5*. The complete notation is marked on several of the cards in the illustration. In broad outline this arrangement corresponds to that in the colour triangle; in the middle are all the very unsaturated colours (groups *dc* and *ec*), while towards the edges the colours become progressively more saturated (groups *oc* and *pc*).

If now each of the two halves of each card is illuminated with a different type of light, the degree of equivalence can be expressed numerically, viz.;

0: No difference;
1: Just perceptible difference;
2: Distinct difference;
3: Very marked difference (the sensation of an entirely different colour is created).

If the numbers ascribed to the different cards are plotted in fig. 5, we get a specific region *3* of very slight agreement, a region *2* of moderate agreement, a region *1* of good agreement and possibly also a region *0* of perfect equivalence. Fig. 5 show the results of a comparison between a daylight lamp (incandescent electric lamp with special blue bulb, see also fig. 1, curve *8*) and ordinary daylight. The unsaturated colours are still badly reproduced, and of the saturated colours purple is the least satisfactory. The direction of colour displacement is shown in the diagram by arrows. Purple is reproduced with a little too much red, the green is too much akin to yellowish-green, and the blue

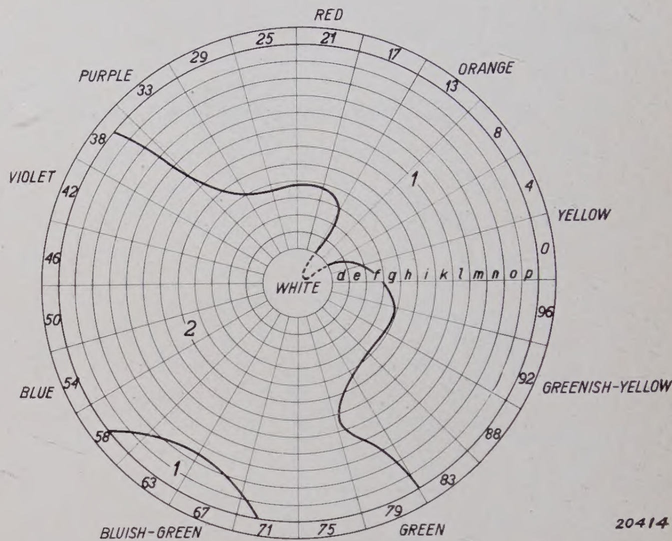


Fig. 7. Comparison of colour reproduction with a mercury-neon-fluorescent compound source with that obtained with daylight.

is a little too unsaturated. These deviations are mainly due to the fact that the daylight lamp still gives too little light at the shortest visible wave-lengths (see fig. 1).

Fig. 6 shows a comparison between a mercury lamp to which red has been added in the form of neon light, and daylight. Here there is a very large region of unsatisfactory colour reproduction, the reason for this being, as already indicated, the large gaps in the spectrum.

Fig. 7 compares daylight with a similar mixture of mercury and neon, but which has been improved by the use of a carefully-selected fluorescent bulb and accurate adjustment of the quantity of neon light. Region *3* has here just completely disappeared, and colour reproduction is throughout satisfactory. In fact with light from this source the surroundings appeared perfectly "natural". The gaps in the mercury spectrum were adequately filled by the neon light and the fluorescent light.

Finally, *fig. 8* compares daylight with a "blended-light" lamp (70-watt super-high-pressure mercury vapour supplemented with a 150-watt incandescent electric lamp). The dearth of red rays in the mercury lamp has here been made good by the excess of red light afforded by the electric lamp as compared with daylight (fig. 1, curves *1* and *3*). Here again there is a definite region of unsatisfactory colour reproduction, although this lack is of a different character to that found in the daylight lamp in fig. 5.

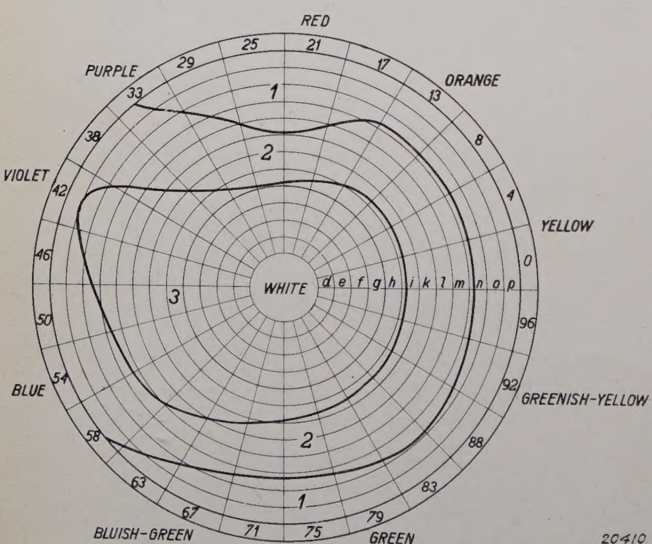


Fig. 6. Comparison of colour reproduction with a mercury-neon compound source with that obtained with daylight.

[7]) Regarding the definition of the terms "degree of saturation" and "dominant wave-length", see Philips tech. Rev. 1, 283, 1936. The degree of saturation and the dominant wave length of the colours here intended are those which the cards possess in daylight.

What is the relationship between the coefficients *0, 1, 2, 3* and the number of "steps" in colour divergence? This relationship was found by a comparison of incandescent electric lamps which were fed with different voltages (i.e. black bodies with different temperatures). It was established that the coefficient *0* corresponds roughly to a difference of 0—1 steps, coefficient *1* to from 1 to 3 steps, coefficient *2* to from 3 to 5 steps and coefficient *3* to from 5 steps onwards.

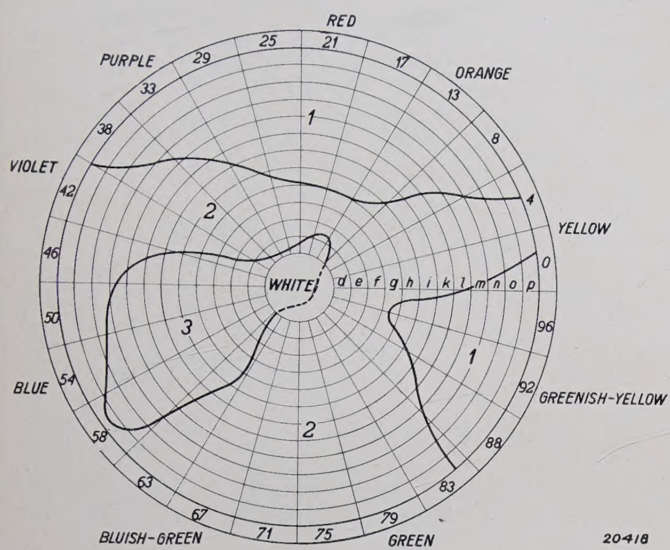


Fig. 8. Comparison of colour reproduction with a compound source made up of mercury light and an incandescent electric lamp, with that obtained with daylight.

The necessity for the complete suppression of region *3* thus coincides with the requirement stated above that the colour difference must not exceed 4 steps.

We thus see that it is indeed possible to obtain such high quality of colour reproduction with gas discharge lamps and fluorescent light (fig. 7). The light output of such a "daylight combination" may be higher than that of an ordinary incandescent lamp, while that of the earlier types of daylight lamps (incandescent lamps with coloured bulbs) was much smaller than the output of the ordinary incandescent lamp.

In many cases where the need for a correct colour reproduction is not so pressing a combination of mercury light and incandescent light (fig. 8) will already be found quite satisfactory.

ILLUMINATION AND ARCHITECTURE

By L. C. KALFF.

Summary. The intended appearance of the artistic forms employed in architecture is in many instances only brought out when they are suitably illuminated. The corresponding results obtained with daylight have been understood and utilised by architects from the earliest times. The innumerable applications and types of artificial lighting available at the present day open up a host of avenues for arriving at similar results with artificial sources of light, some of which have already been fully explored and the results applied in practice, while in many others only the threshold has been crossed and full development is reserved for the future.

Fig. 1. (Left) A building in the Doric style as seen in sunlight. All forms and profiles stand out with their true values. It is distinctly seen how e.g. the flutings and the cornice have been designed entirely on the marked contrast between light and shadow.

Fig. 2. (Right) The same building when seen in diffuse daylight loses all plasticity in its finer profiles and hence the characteristic appearance which the architect had intended.

An analysis of the relationship between illumination and architecture brings us to the conclusion that these two concepts are inseparably linked with each other. To state this fact may appear superfluous, although a number of interesting consequences accrue from it. Long before technological developments enabled electricity to be used for the illumination of architectural works, architects have been building for thousands of years and from the very first had functioned as what might be termed "illumination architects", i.e. daylight or sunlight architects. Some explanation of this aspect of the subject is perhaps necessary.

Every artistic form, which has been evolved on aesthetic lines from practical or other considerations, must be illuminated in a perfectly definite manner in order to reveal to the spectator its specific details of beauty, in other words the forms and plastic motifs of a building can be suitably enhanced in accordance with the aims of the artist by employing an appropriate illumination. That from the very outset every architect based his designs on a specific daylight illumination may be readily demonstrated with the aid of a few examples.

Examination of the different architectonic forms, profiles and ornaments as found in different parts of the world under different climatic conditions, will show that architects in different countries in evolving their designs have been guided strictly by the distribution of daylight prevailing in each particular country and associated with the climatic conditions obtaining there.

Thus it is seen in Egyptian and Assyrian architectural and plastic motifs *(fig. 3)* that in these countries with their abnormally dry climate and very bright and even harsh sunshine preference has been given to particularly pronounced forms and plastic designs ,while ornamentation has been limited to extremely shallow bas-reliefs which when illuminated by bright sunlight reveal a very striking and sharp delineation, even when cut only a few millimetres deep. The same principle is found to have been followed in the artistic productions of Ancient Greece, and it is interesting to note that bas-reliefs of this type are not found in countries further north where the same harsh sunlight is absent and where the sky is comparatively cloudy or overcast and the incident light would be too weak to bring out the finest architectural details.

A typical example of highly-refined "illuminated" architecture is offered by the Greek temples. In the profile of a frieze shown in *fig. 1* it may be seen how the angle of incidence of the sun's rays has been taken into account so that certain parts of the profiles lie in shadow, while again others are brightly illuminated; a modillion for example must stand out in the light against a shaded background, so that each individual modillion constitutes an illuminated unit in the long dark border of the frieze. It is noteworthy that the same profiles which are employed in the frieze behind the front

Fig. 3. Assyrian architecture with its bas-reliefs in stone or terra-cotta also brings out the characteristic features suited to a sunny climate.

row of columns in the peristyle exhibit entirely different forms. It is evident that there no part of the frieze receives the sun's rays, so that the only illumination consists of the sunlight reflected from the ground and the steps of the temple, which although powerful is yet markedly diffused. For this reason the profiles of these interior friezes have been modelled much deeper and with more emphasis, so that even in their location in a half-light their plasticity is yet prominent. On an examination of *fig. 2* it becomes still more clearly apparent that the architecture of the temple has been based on sunlight as the medium of illumination. In this photograph taken with an overcast sky the plasticity of the lightly modelled profiles is absent, and as a result one of the characteristic beauties which the architect had undoubtly intended has become lost.

If we pass to the more northern countries where an overcast sky, fogs and diffuse daylight are of common occurrence, it may be seen, for instance, on Gothic architectural monuments that extremely deep profiles and heavy ornamentation have been employed in order to obtain the desired effects of light and shade with the diffuse illumination there available. An excellent example of this fact is the Hotel de Ville (Town Hall) of Louvain *(fig. 4)* with its living silhouettes, its carved stones and balustrades and deeply chiselled relief. If an architectural masterpiece of this kind were transplanted to the harsh sunlight of Egypt, the greater part of its intrinsic beauty would be lost owing to the pronounced and heavy contrasts obtained between the excessively emphasised light and shadow effects.

A further characteristic consequence of the prevalence of diffuse lighting in northern countries lies in the preference shown for colour contrasts rather than contrasts produced by plastic modelling. An apt example of this is the typical bright exteriors of the burnt-clay and sandstone structures which in the Dutch Renaissance styles gave a much more characteristic appearance to the facades than mere sculptural ornamentation. Also in Germany, Sweden and Great Britain many examples are met where colour contrasts have been employed in place of plastic effects. On the other hand, examination of an Italian palace, such as the Palazzo Pitti, which has been built of a grey stone, reveals that here in the south the mere contrast between light and dark areas already produces a very fine effect.

On comparing a variety of modern applications

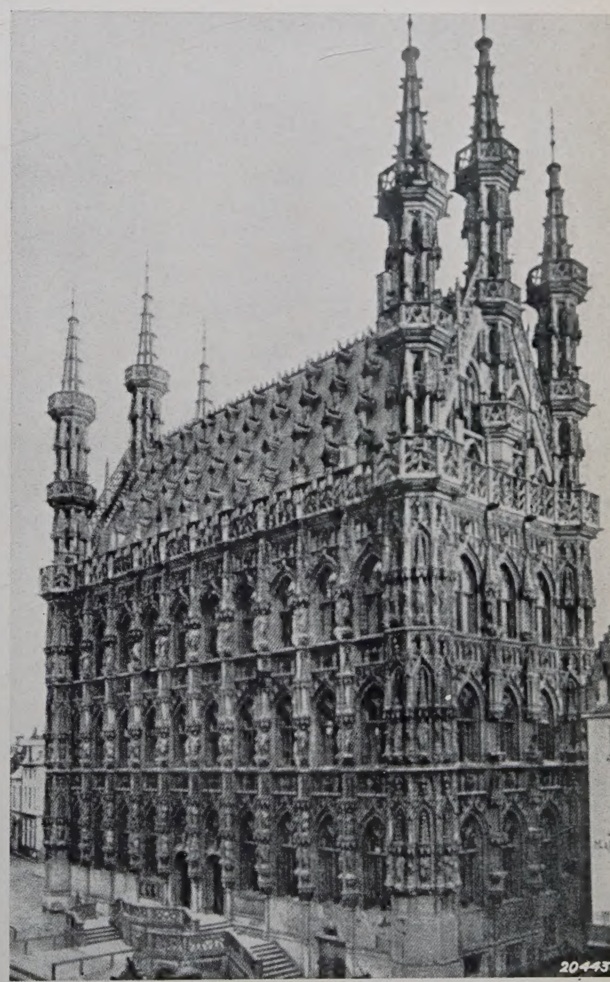


Fig. 4. North European Gothic structures, of which the Hotel de Ville at Louvain is an excellent example, reveals a living silhouette effect, stone balustrades and very deeply engraved reliefs and profiles, since the prevalence of dull weather makes these pronounced contrasts essential in order to obtain the desired effect.

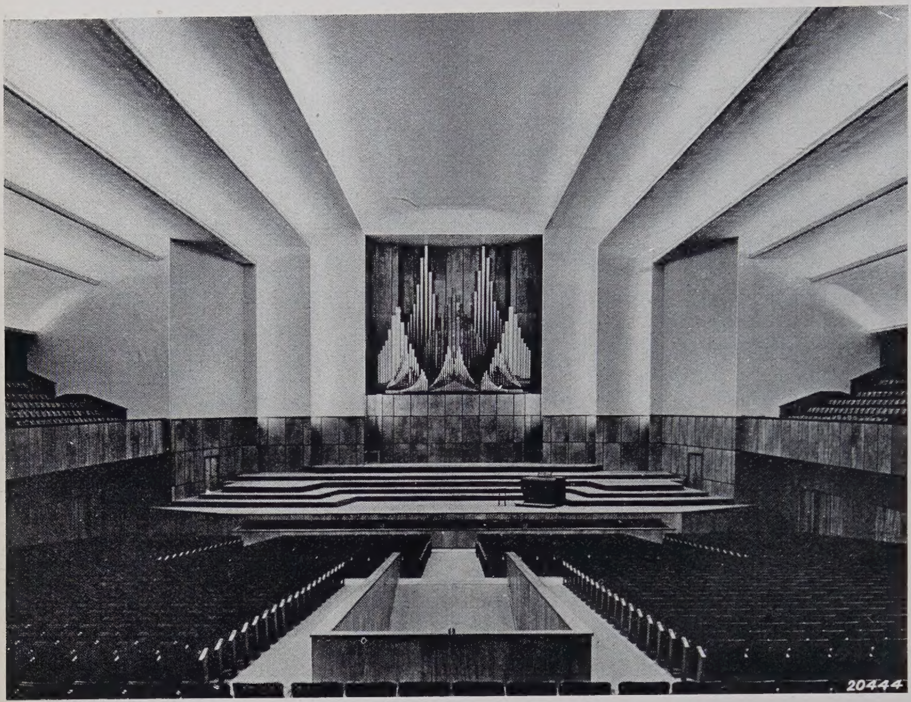


Fig. 5. The Festival Hall of the Brussels World Exhibition, architect Van Neck, reveals a design determined to a large extent by the system of artificial illumination adopted.

of artificial illumination with the experienced use which has been made for years with natural light, it is realised that hitherto artificial illumination and architectural considerations have only very rarely been considered in the light of their mutual relationships. When floodlighting the profiles and friezes of a classical work of architecture, the floodlights are nearly always directed from below upwards, thus destroying all surfaces in shadow as worked out and intended by the architect. The frieze on the building acquires a flattened effect as a result of this illumination, the shadows disappear under the window sills and along the sides of the windows, and the greater part of the shadows produced by artificial illumination is almost invisible to the spectator who nearly always is looking in the direction of the light itself. Another example is offered by the classical interior whose forms have also been based on illumination by sunlight. An examination of such interior decoration when illuminated by an electric lamp suspended in the centre of the room reveals no shadows at all, and the only means of seeing the plastic design is offered by heavy deposits of dust collecting in the deeper hollows, the dust becoming visible owing to its difference in colour.

As long as the available light source remained weak and also evolved a large amount of heat, its most practical position was in the middle of the room, where everyone could conveniently gather round the light, so that full use could be made of the expensive and weak illumination and at the same time the danger of fire was reduced to a minimum owing to the light being at its maximum distance from the walls and ceiling. But the net result of this central position for illumination is, as has

Fig. 6. The bar in the Capitol Theatre, Madrid, has also been exclusively designed from considerations of illumination technology.

already been indicated in the case of one of the classical examples referred to above, that only few shadows are obtained in the interior ornamentation. For this reason only a limited amount of plastic modelling was employed for these interiors, and the principal effect was obtained by a suitable choice of materials and colours. Daylight illumination has always been of unreliable quality and every consideration had to be given to the location of the room in regard to the direction of the wind and the ever fluctuating outdoor illumination, whose intensity depends on the time of the day and can therefore not be calculated *a priori.*

Fig. 7. Colonial Museum, Paris, a work of the architects Jaussely and Laprade, has a facade which has in fact a better appearance during the night than in daylight. The lights mounted behind the breastwork not only afford a very fine illumination of the bas-reliefs of the walls, but also the stepped profiles under the cornice have been designed for this form of illumination. Particularly successfull is the sihouette effect of the columns.

Fig. 8. The giant candelabrum of the Roxy Theatre in New York is not only an interesting lighting ornament, but also reveals shadow edges and decorative bas-relief which are only brought out by the grazing light rays.

In this direction there are innumerable potential applications for modern methods of artificial lighting. At no excessive cost incandescent electric lamps afford a high light output, while their wide ranges of shape and intensity with almost a complete absence of the danger of fire permit them to be placed in their optimum interior positions, and the direction and intensity of the light radiated to be accurately estimated *a priori.* In modern interior decoration we can therefore take as a basis the same general principles as adopted in previous centuries by architects and designers who only had to make provision for daylight illumination.

Naturally for daylight illumination we have almost unconsciously learnt how to give due consideration to the interplay of light and shadow so as to give life to plastic ornamentation and surface design, while to achieve the same natural result with artificial light remains a problem of the future.

Electric incandescent lamps, arc lamps, discharge tubes, etc., are now marketed with so many different shapes and output ratings that a suitable lighting unit can be selected for practically any purpose. But in this connection the appearance of the building under illumination by each light source and the impression made on the spectator by the resulting effect are points which require consideration. What is the most suitable illumination for each particular case? What impression and psychological effect

have to be produced? Is the whole of the light to be reflected from the ceiling downwards; must the walls be lit up or is the room to be divided up by rich ornaments in order to form a silhouette? In what direction shall the gaze be attracted and shall this be done by adopting a colour contrast or by more intensive illumination? How do our moods react to coloured light, and how can we create a specific psychological effect? These are only a few of the innumerable problems which have to be solved.

The only true medium for plastic art has hitherto been exteriors where the interplay of light and shadow brings out to the full the many nuances associated with profiles, ornaments, bas-relief, niches, joints and entablatures. In past years these forms were introduced also into interior decorative schemes quite indiscriminately, with the result that the weak and usually centrally-situated light sources to a great extent neutralised the desired effects incorporated in design. Contrasts in colour and materials had then to be adopted as supplementary motifs. But with artificial light it has now become possible to create these effects in interiors exactly as realised with exteriors and even with more pronounced results. We have here a new mode of artistic expression with which we can in the first place gain practical experience and then incorporate the results in our architectural designs. Naturally the adoption of this system of lighting requires entirely new methods of construction, which at the present time have been followed in only isolated instances. These new principles imply the adoption of entirely different cross-sections for our buildings as compared with those adopted hitherto, and it will take many years before we are sufficiently skilled to apply this new method of interior decoration faultlessly and with as much facility and understanding as for exteriors.

The object of the present article is to indicate the new direction of architectural evolution and to convince the architect of the urgent necessity of a close study of its potentialities and applications in the light of modern technology. Examples of some modern designs are shown in *figs. 5* to *8*, in which the spacial forms and the lighting equipment have been rationally adapted to each other. Developments in this direction will continue unhaltingly; those who do not keep pace with them will be regarded as retrograde and their work soon forgotten, while those realising their import and significance will be abreast with the times and produce works of art infused with life.

THE PHOTO-ELECTRIC EFFECT AND ITS APPLICATION IN PHOTO-ELECTRIC CELLS

by M. C. TEVES.

Summary. This article discusses the principles of photo-electric phenomena. The external photo-electric effect is dealt with in greater detail, being followed by a description of technical developments culminating in modern photo-electric cathodes.

Introduction

About a century ago (1839) E. Becquerel discovered that an electromotive force is generated between two metal plates immersed in an electrolyte when these plates are illuminated. W. Smith in 1873 observed that the electrical resistance of the semi-conductor selenium varied when light was directed on it. In 1876 W. G. Adams and A. E. Day investigated the occurrence of electric currents when selenium connected in an electric circuit was exposed to light, while finally in 1887 W. Hallwachs prompted by an observation of H. Hertz on the diminution in disruptive voltage on illuminating the electrodes with light from another spark gap, observed that a negatively-charged plate loses its charge when it is exposed to ultra-violet light. If the plate is positively charged no discharge takes place. P. Lenard and J. J. Thomson demonstrated that the light induced the ejection of electrons from the plate. This group of phenomena is termed "photo-electric".

Those phenomena observed to take place with selenium in which the electrical process is located within the illuminated body are grouped together under the general term of the internal photo-electric effect. But if electrons are emitted from the illuminated surface, as in the last-mentioned experiments of Lenard and Thomson, the behaviour in question is classed as an external photo-electric effect.

In the present article we shall limit ourselves to a discussion of the latter effect. The ejected electrons issue from the plate with a specific velocity and can therefore overcome a potential difference. It is, however, surprising that the potential difference V_{max}, which is just able to retard and arrest the fastest electrons, is not determined by the intensity but exclusively by the frequency of the light, according to the equation:

$$V_{max} = \text{constant}\ (\nu - \nu_0).$$

Light with a frequency lower than ν_0 is no longer able to induce the ejection of electrons. ν_0 is termed the "limiting frequency" or also the "red limit" of the photo-electric effect. It is a constant for each substance.

This fact is difficult to interpret with the aid of the electromagnetic theory of light, for in some way or other the electric-field intensity of the light must be responsible for the emission of an electron from the cathode. But this field intensity is determined by the intensity of the light rays and is independent of the frequency.

A similar difficulty is encountered, moreover, in regard to other photo-effects. In the action of light on a photographic plate there is also a frequency threshold value below which the light produces no effect at all. Again in relation to its physiological effects the frequency of light is frequently of greater moment than its intensity. It is evident that the electromagnetic theory of light is incomplete in these directions.

This shortcoming is overcome by the assumption that light energy can be radiated or absorbed only in specific amounts, "quanta", of the value of $h\nu$ (i.e. a constant times the frequency). h is the socalled Planck's constant and is $6.55\ 10^{-27}$ erg per second. To liberate electrons from a metal a specific amount of energy E is required which can only be derived from the radiation when these quanta $h\nu$ are $> E$, i.e. when ν exceeds a definite value of ν_0. If $h\,\nu > E$ the excess energy is converted into kinetic energy of the emitted electrons.

From these considerations Einstein in 1905 deduced the famous equation:

$$\tfrac{1}{2}\, m\, v_{max}^2 = h\,\nu - E = h\,(\nu - \nu_0) \quad . \quad (1)$$

where e is the charge, m the mass and v_{max} the maximum velocity of the emitted electrons. The energy $E = h\nu_0$ can be expressed with the aid of equation $h\,\nu_0 = e\,V_0$ in the form of a potential fall V_0, which the electrons have to overcome on being emitted from the metal.

In Table I the value of the potential fall V_0 is given in volts for a number of metals, as well as the "red limit" in Ångstrom units (1 Å = 10^{-8} cm).

Table I

Metal	Work-function in volts	Red limit in Å
Silver	4.61	2680
Gold	4.90	2520
Cadmium	4.00	3100
Mercury	4.53	2735
Tungsten	4.50	2700
Molybdenum	4.15	3000
Platinum	6.30	1960
Lithium	2.28	5400
Sodium	2.46	5000
Potassium	2.24	5500
Rubidium	2.15	5700
Caesium	1.90	6500

For a given spectral composition of the light the photo-electric current is proportional to the intensity. The response to the light takes place without lag, i.e. the photo-electric effect follows all fluctuations in intensity without measurable delay, even when fluctuations in time take place of the order of 10^{-8} sec.

If all the electrons emitted from the photo-electric cathode are diverted to the anode by a sufficiently powerful field, a "saturation current" is produced which is proportional to the number of light quanta incident per second, i.e. to the intensity of the light, provided of course that the frequency is above the value ν_0 defined by Einstein's equation. Furthermore, the current intensity is determined by the probability of absorption of light quanta resulting in the

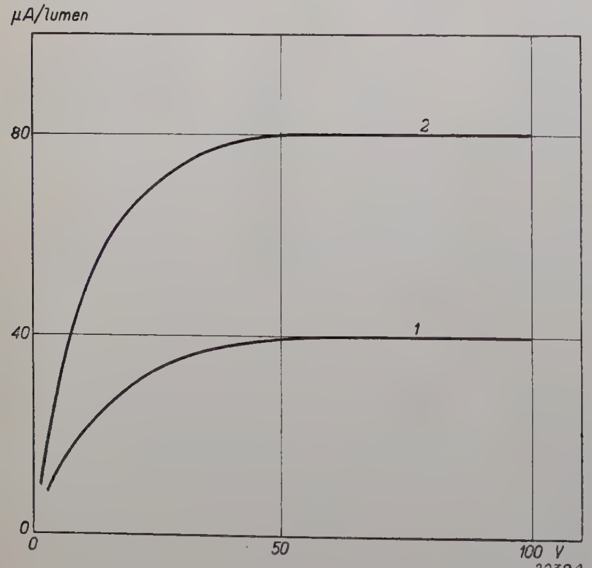


Fig. 1. Photo-electric current per lumen plotted as a function of the anode voltage for two different modern photo-electric cathodes of the type with caesium oxide deposited on silver in a vacuum. *1* Standard base; *2* special base. The curves apply for incident light from an electric lamp burning at a temperature of 2600° K.

emission of an electron, such probability being governed by the wave length of the light.

In *fig. 1* the variation of photo-electric current per lumen is plotted against the anode voltage for two different modern types of photo-electric cathodes. It is seen quite clearly that also with these (non-metallic) cathodes a saturation current is reached as the voltage is raised.

The following simple calculation will give an idea of the possible order of magnitude of the saturation current. We take as wave length λ = 7000 Å or ν = velocity of light/wave-length = $0.43 \cdot 10^{15}$ sec^{-1}, i.e. the long-wave red, since modern photo-electric cells usually exhibit their maximum sensitivity in this frequency range. A quantum $h\nu$ of this radiation has an energy of $6.55 \cdot 10^{-27} \times 0.43 \cdot 10^{15} = 2.81 \cdot 10^{-12}$ erg. Thus with 1 watt, $10^7 \div 2.81 \cdot 10^{-12} = 3.56 \cdot 10^{18}$ electrons can be liberated. In terms of current this is equal to $1.59 \cdot 10^{-19} \times 3.56 \cdot 10^{18} = 0.566$ A. Actually in practice a sensitivity of not more than a good 1/500 of this sensitivity has hitherto been attained, as is shown for instance in the curves reproduced in *fig. 2*. Similar to those in fig. 1 these curves also apply to modern photo-electric cells, the characteristics of which will be discussed later in this article. The photo-electric currents of pure metals are much smaller still.

With the illumination from an electric lamp curve *1* in this figure corresponds to an output of 80 μA per lumen. For practical purposes, however, the currents obtained with this sensitivity will frequently prove inconveniently small (see e.g. the estimate made in the article "A surveillance system using infra-red rays" [1])). It is therefore extremely important as regards their technical applications that the efficiency of photo-electric cells is made as high as possible.

The curve which gives the variation in sensitivity as a function of the frequency of the incident light, is termed the spectral sensitivity curve, examples of which are reproduced in fig. 2. Along the ordinate the photo-electric current divided by the incident energy in mA per watt is plotted, and along the abscissa the wave length in microns, the frequency and a scale in "electron volts", the latter giving the potentials in volts corresponding to the frequencies in accordance with the equation $eV = h\nu$. It is seen that the red limit for both cathodes is situated at a wave length of approximately 1.5 μ, or at a frequency of 2.10^{14} cycles per second or at 0.83 electron volt. In the same

1) A. L. Timmer and A. H. van Assum, Philips techn. Rev., 1, 306, 1936.

way the maximum sensitivity for both cathodes can also be stated in each of these three scales.

Technical Developments

When employing the photo-electric effect the chief aim is to obtain the maximum current with the specific light source available. The light source is in nearly all cases an electric lamp of which the bulk of the energy radiated lies in the infra-red region of the spectrum.

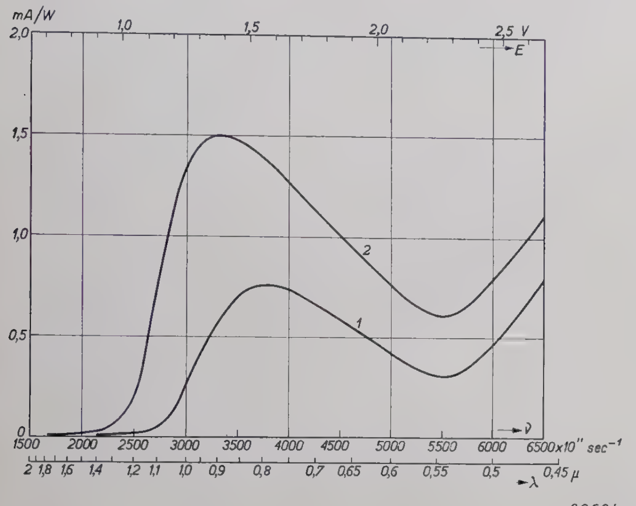


Fig. 2. "Colour sensitivity curve". Photo-electric current plotted against the frequency of the incident light for the same types of photo-electric cells for which the photo-electric current is given in fig. 1.

It is seen from Table I that only the alkali-metals lithium, sodium, potassium, rubidium and caesium, have their red limit located in the visible part of the spectrum, that of caesium being displaced furthest towards the red. These elements are insensitive to infra-red radiation. The maximum sensitivity for potassium is at 4350 Å, for rubidium at 4800 Å and for caesium at 5400 Å. Even when using a caesium cell, only 3 to 4 per cent of the light radiated from an electric lamp has a sufficiently high frequency to cause photo-electric emission. According to the table other metals are still less suitable.

Elster and Geitel found that, as a result of passing an electric discharge through hydrogen in contact with potassium deposited on the walls of a bulb, a photo-sensitive layer was formed whose red limit was displaced towards the red by several thousand Ångstrom units as compared with that for untreated potassium. These cells are termed "hydrogenated cells". Since the red limits of caesium and rubidium correspond to still longer wave lengths it was to be expected that hydrogenated cells of these metals would exhibit a more satisfactory behaviour than those of potassium. The stability of hydrogenated rubidium and caesium cathodes was, however, found to be unsatisfactory at ordinary temperatures.

In the development of the modern photo-electric cell another method was therefore adopted. Langmuir and Kingdon had found that the emission of electrons from incandescent filaments, e.g. those of tungsten, could be considerably increased by coating their surfaces with electro-positive metals, such as the alkaline earths (Ba) or alkali-metals (K, Rb or Cs).

If a tungsten filament on which a thin coating of caesium has been deposited is heated in a vacuum, electrons commence to be emitted already at 300 °C. If the temperature of the wire is gradually raised this emission increases, reaches a maximum and then begins to drop again when a temperature of about 700 °C is attained, at which the caesium is volatilised from the wire.

That the caesium atoms remain on the wire up to a high temperature is demonstrated by the fact that they are attached to their base with considerable cohesion. It is assumed that they are ionised and that an electron is given off to the underlying tungsten. The ionized caesium atoms build up a positive surface charge and so decrease the work done in the emission of the electron. This is shown in *fig. 3*. The electron enters an accelerating field as soon as the last tungsten atoms are passed, which facilitates the emission. This reduction in work done, which was originally observed on the emission of electrons from incandescent filaments, also applies to the photo-electric effect.

If the tungsten is coated with a layer of negative ions, for instance by absorption of oxygen atoms, the reverse process takes place: emission is rendered more difficult, and the voltage drop V_0 increases.

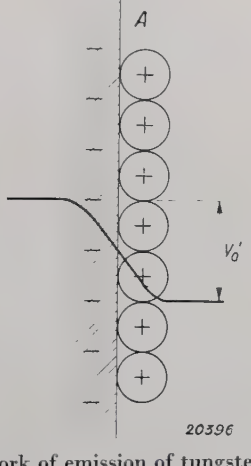


Fig. 3. Effect on work of emission of tungsten due to adsorbed caesium atoms. The caesium atoms deposited on the tungsten give up their electrons to the tungsten, and as a result an electrical double layer is formed. The electrons issuing from the tungsten encounter an accelerating field V_0' which lowers V_0 and so facilitates their emission.

Ives and other investigators found that surface coatings of electro-positive metals are also very useful for inducing photo-emission, and the red limit is displaced far into the infra-red region. Koller described the combinations: silver—monatomic oxygen layer—monatomic caesium layer, whose red limit has still a greater wave length.

Still another method was adopted by De Boer and Teves who based their work on the following considerations:

To obtain a high photo-electric current it is desirable:

1. To reduce as far as possible the work required for emission.
2. To increase as far as possible the efficiency, i.e. the percentage of absorbed light quanta which result in effective photo-electric emission.

The first condition leads, as already indicated, to the use of strongly electro-positive metals. But from the point of view of the second condition metals are not very suitable, for their electrons are extremely mobile, so much so that the greater part of the light energy promotes motion of the electrons and is lost in the form of heat. The photo-electric effect in insulators gives a much better efficiency. When light is absorbed by free atoms (in a gas) each absorbed light quantum actually liberates an electron, if the energy of the light quantum is greater than the ionisation energy.

The purpose of the investigations carried out by De Boer and Teves was to influence the photo-electric effect on solid surfaces in this direction, viz., by the adsorption of caesium on deposited coatings of salts. In the first instance barium fluoride coatings were used for this purpose, being deposited by sublimation *in vacuo* so as to obtain a laminated structure with a large surface (about 100 times greater than with a compact structure). This surface thus had a large number of areas exhibiting a very marked adsorption. Later oxides were used in place of the salts and these proved more efficient still.

The mechanism here responsible for the emission of photo-electrons differs fundamentally from that occurring with metals. The alkali-metal atom adsorbed at the insulating oxide layer behaves with respect to light similar to a free atom in a gas, except that the ionisation energy has been altered by adsorption. A light quantum can ionise this atom and the electron can as a result pass out into the vacuum. The photo-electric effect in this case depends on this process.

When an adsorbed atom has become ionised and an electron has been emitted, a positively-charged metallic ion remains. This must be neutralised before it can again participate in the emission process. But a neutralising electron cannot be withdrawn without further ado from the insulating coating, since this would merely result in a displacement of the charge. The electron must therefore be extracted from the metal substratum. This is indeed readily possible, if the thickness of the insulating coating does not exceed 100 to 1000 molecules, viz., by the field generated by a positive ion becoming sufficiently powerful to draw an electron directly from the underlying metal.

If the oxide layer still contains free metal, these particles can act as intermediate carriers, while if the conduction mechanism has been inadequately developed or has become overloaded by an excessive withdrawal of current, fatigue phenomena may set in since unneutralised positive charges remain extant in the layer. By inserting an additional metal particle the conduction mechanism is improved and the yield can be considerably increased.

A decisive factor in the choice of the insulating coating is the desire to reduce as far as possible the ionisation energy of the adsorbed alkali-metal atom. The best results in this direction are obtained with caesium oxide.

The optimum composition determined as a result of prolonged experiments consists of a silver mirror which is oxidised to silver oxide by a glow discharge in oxygen and then exposed to the action of caesium vapour. The caesium is converted to a caesium oxide, while the liberated silver remains in a very finely divided state and as already indicated increases the conductivity.

Table II gives the sensitivities of various photo-electric caesium cells, as well as the wavelength range corresponding to maximum sensitivity, and the red limit. The sensitivities have been expressed in μA per lumen, using light from a tungsten lamp operating at a temperature of 2600 ° K.

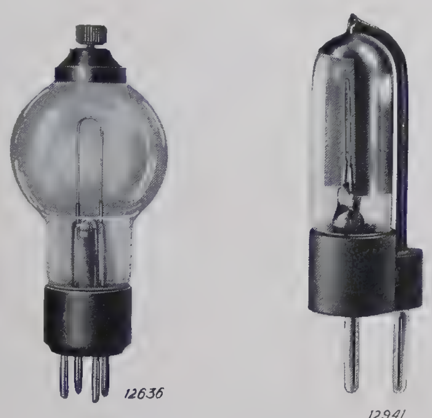
Table II

Sensitive layer	Max. Sensitivity approx.	Wave-length of max. sensitivity	Red limit
	μA/Lumen*	Å	Å
Pure caesium	0.15		6300
Ag with monatomic coating of O_2 and Cs	1.5	3500	8000
Ag with pure Cs_2O and Cs (monoatomic). . .	12	6100	11500
Same with Ag in Cs_2O	20	7000—8000	12000
Same with additional Ag in Cs_2O.	30	7500—8000	12000
Same with additional Cs in Cs_2O.	40	7500—8000	14000
Same with additional Ag and additional Cs in Cs_2O	55	7500—8500	17000

[1]) For light from a tungsten lamp burning at 2600 °K.

The efficiency i.e. the ratio of the number of photo-electrons emitted to the number of light

quanta incident on the cell, is about 1 : 100 for the most sensitive cell using the most suitable light source. This ratio is still very much less than 1 : 1. Thus only a small fraction of the incident



a) b)

Fig. 4. Photo-electric cell with caesium cathode:
a) vacuum cell, type 3512;
b) with rare gas filling, type 3530.

light quanta is absorbed by the adsorbed caesium atoms; this is partly due to the fact that the bulk of the light is absorbed by the coloured covering surface.

In many cases the photo-electric current can be further intensified by filling the cell with a suitable rare gas: ionisation of the electrons by collision with the atoms of the rare gas then ensures that under favourable conditions an average of about 20 electrons reach the anode for each electron emitted from the photo-electric cathode. In this way 100 to 200 μA per lumen can be attained with low currents for long periods.

Disadvantages of the gas filling are its inertia, a result of the time required for ionisation to develop, also the fact that there is no linear relationship between the photo-current and the electron current, as well as the greater fortuitous fluctuations in the electron current with constant light intensity, this latter resulting in a disturbing noise.

Fig. 4 shows two photo-electric cells with caesium cathodes: a) a vacuum cell, and b) a gas-filled cell. *Fig. 5* gives the mean photo-electric current in μA per lumen for standard gas-filled caesium cells. No saturation current occurs with these cells. The current, which increases with the voltage eventually causes an arc owing to the steady increase in ionisation, i.e. to a passage of current which is maintained also in the absence of any incident light.

For both types of cells the permissible load is 5 μA per 100 sq. cm. of cathode surface. After 1000 hours the sensitivity is then still 60 per cent of the initial value. The arcing voltage of the gas-filled cell is 150 volts in the dark, and the working voltage 100 volts. In the dark the current spontaneously emitted from the cathode (the socalled dark current) is 10^{-10}A per sq. cm. of cathode surface. At temperatures from 15 to 30 ° C this dark current rises by 10 per cent per degree.

For ultra-violet light, with for instance wave lengths below 4000 or 3000 Å, other cells are employed, viz., sodium cells for below 4000 Å and cadmium cells for below 3000 Å. Below 3500 Å a jacket of glass permeable to ultra-violet rays must be used, while below 2800 Å quartz is necesary.

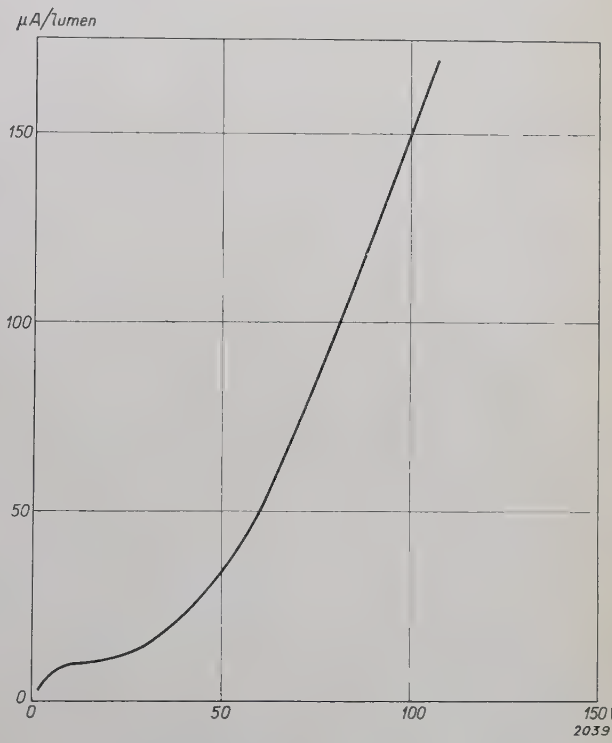


Fig. 5. Photo-electric current per lumen plotted as a function of the anode volts for a gas-filled cell. Contrary to the curves for vacuum cells (fig. 1) this curve exhibits no saturation as the anode voltage increases.

SPECTRAL DISTRIBUTION OF THE RADIATION FROM THE "BIOSOL"

By A. VAN WIJK.

Summary. Short description of the "Biosol" and supply arrangements, followed by a discussion of measurements of the spectral intensity distribution. The spectral sensitivity curves for various biological and therapeutic applications of ultra-violet radiation are also discussed and as far as permissible conclusions are drawn regarding the efficacy of the "Biosol".

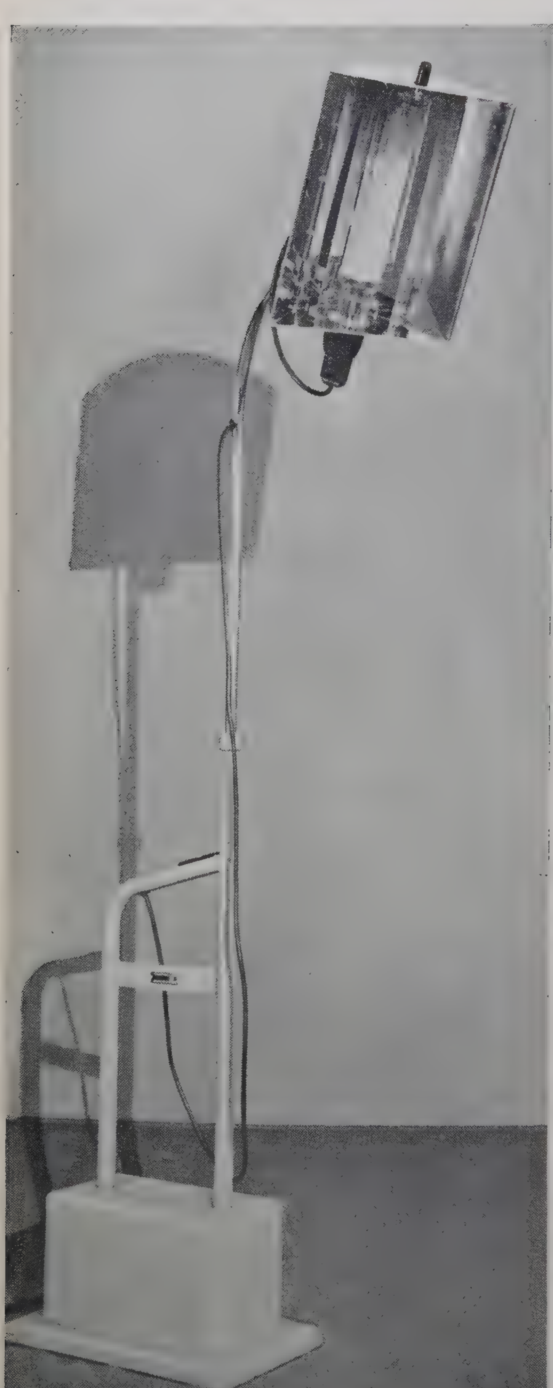


Fig. 1. Philips "Biosol" Irradiation Unit.

The "Biosol" and Supply Arrangements

The "Biosol", which was primarily evolved for medical purposes, is a tubular quartz lamp in which an arc discharge through mercury vapour is generated between electrodes. The density of the mercury vapour is maintained constant, during the operation of the lamp, while the vapour pressure is of the order of 1 atmosphere. Two types of lamp are made: Type A rated for 250 watts and Type B rated for 475 watts. In general the "Biosol" is connected directly to an A.C. supply through a choke coil (for voltages from 200 to 260 volts). In the case of an A.C. supply below 200 volts the lamp is connected up over a transformer. The choke coil or transformer is accomodated in the base of the lamp stand which supports the lamp and its reflector. The latter is chromium plated on the inside and can be adjusted both in height and direction *(fig. 1)*. It is made up of six facets arranged at such angles to each other that the radiation reflected from each facet is focussed on the same strip, 40 cm wide, situated 50 cm in front of the lamp *(fig. 2)*. In this way a very uniform distribution throughout the irradiation field is obtained, also at a greater distance from the lamp *(fig. 3)*.

The lamp in most cases lights directly the current is switched on; if it does not doso, a push is operated so that a higher potential is applied to the lamp for a short time. The circuit is shown in *fig. 4*. To obtain the higher voltage required for ignition, operation of the push connects a small transformer in series with the mains supply. The current is then limited by a high resistance. A glass filter partially transmitting ultra-violet rays can also be fixed over the lamp; it absorbs the greater part of the shorter ultra-violet rays (below approximately 0.28 μ) but allows the longer rays to pass through, thus adapting the lamp to other biological purposes. The spectrum of the "Biosol" with and without the filter is shown in *fig. 5*, from which it may be seen that a line spectrum is obtained.

Dosage Control of Ultra-violet Radiation

As soon as we commence to deal with a compound radiation made up of a variety of wave-lengths,

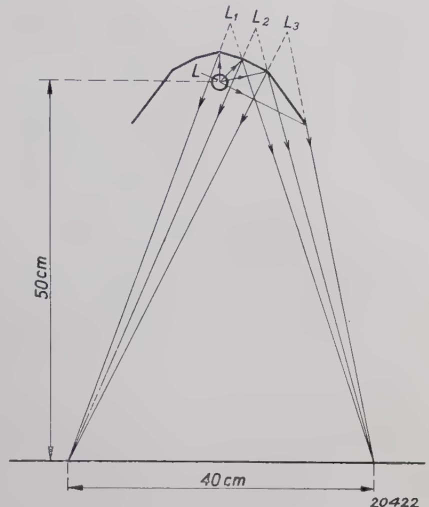


Fig. 2. Concentration of rays with the "Biosol" reflector. The virtual images L_1, L_2, L_3, etc., of the light source L are all projected on to the same strip, 40 cm wide, at a distance of 50 cm.

instead of a simple monochromatic radiation, the estimation of the radiation intensity becomes complex and cannot be determined by the application of any general rules. The evaluation of intensity depends in fact on the nature of the effects and results which are to be achieved with the radiation. Thus, e.g. different compositions of visible radiation, producing an equivalent impression on the eye, are found to have entirely different values when compared as regards their photographic activity, or their influence on the assimilation processus in the green portions of plants. The reason for the different effects produced by

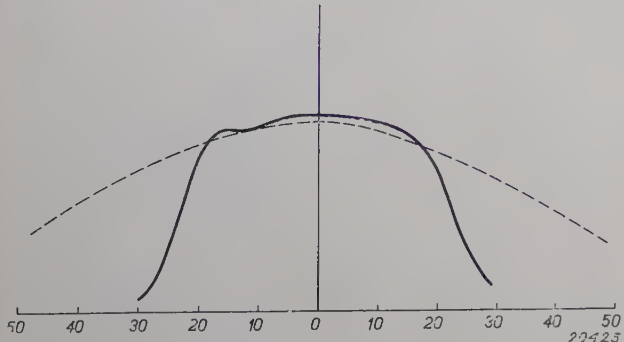


Fig. 3. Relative irradiation intensity in a plane at 50 cm distance from the "Biosol" lamp in the reflector as a function of the distance from the centre of the irradiation field. The curves relate to measurements parallel to the axis of the lamp (broken lines) and perpendicular to it (full lines).

radiations having different spectral compositions is that the action of the radiation on the processes above-mentioned depends on the various wave lengths to different extents. To calculate the action produced by a compound radiation it is necessary to multiply the radiation energy in each wave-length interval by a factor expressing the sensitivity of the particular process under consideration with regard to that wave length, and then add or integrate the result over the whole wave-length range entering into question.

But since the different radiation effects may correspond to different sensitivity curves, the results obtained by such calculation for a specific compound radiation and a specific action cannot be employed *pari passu* for drawing any conclusions of the effect which the same radiation might produce in other processes.

In reference to our introductory remarks regarding the action of a visible compound radiation it must be emphasised that a statement of the intensity of illumination, expressed in lux units, produced by a given radiation on a given surface is no indication of the potential effect on the same

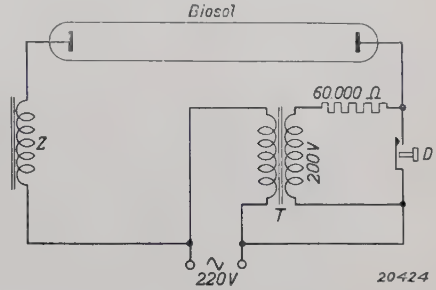


Fig. 4. Circuit layout of the "Biosol" with lighting arrangement. If the push D is not pressed, the contact is closed. The "Biosol" is connected to the 220-volt mains supply through the choke coil Z. The secondary of a small auxiliary transformer is connected up through a 60 000-ohm resistance and the push switch. If the lamp does not light, D is pressed and the secondary voltage of T is then put in series with the mains voltage through the 60 000-ohm resistance, the lamp beginning to burn although the current remains very low (approximately 7 milliamps). On releasing D the direct-on-mains connection is re-established, the current is built up and is then only limited by the choke coil Z.

radiation on the growth of plants or in causing the blackening of a photographic plate. The intensity of illumination may be based on the socalled normal ocular sensitivity curve, which may be taken to be sufficiently valid for every normal individual. For a given photographic plate a similar sensitivity curve can also be deduced, such curve then serving as a basis for calculating the "photographic illumination-intensity" for the particular type of plate under consideration. For other kinds of plates different curves must then be employed.

A similar state of affairs is encountered in estimating the action of ultra-violet radiation when used for biological and therapeutic purposes. The

efficacy of the radiation depends here entirely on the action which it is desired to produce. But in comparison matters are less favourable here, since it has hitherto not been possible to deduce a sen-

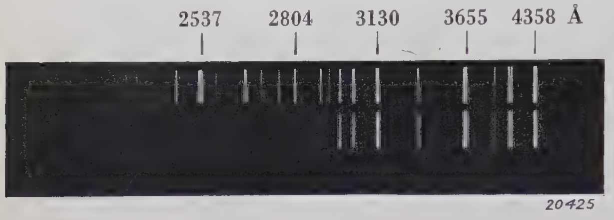


Fig. 5. Spectrum of the "Biosol" with and without filter. Equivalent exposure times.

sitivity curve for every biological therapeutic process entering into consideration. It is in fact doubtful whether standard sensitivity curves, whose validity is reliable as regards normal individuals, at all exist for the various processes in question. But such curves are necessary if we are to evolve a biological unit of irradiation intensity for any specific process, although a knowledge of the corresponding sensitivity curve is not absolutely indispensable for this purpose.

It thus follows that there can be no question at all of introducing a single unit for expressing the intensity of ultra-violet radiation in reference to its biological and therapeutic effects, and that at most it might be possible to introduce a whole series of these units although at the present time no basis for this development has been evolved.

That the biological and therapeutic sensitivity curves for ultra-violet radiation have not been adequately studied in the past is due mainly to the serious experimental difficulties encountered, *inter alia*, in producing sufficiently powerful monochromatic radiations. In addition, there are the ever-present and serious difficulties of carrying out a really quantitative biological experiment. Actually the only relative sensitivity curve which has been sufficiently accurately investigated up to the present is that relating to the socalled erythema effect. It may be recalled here that the term erythema is applied to the redness of the skin exhibited after a few hours' irradiation with a sufficiently powerful dosage of ultra-violet light. If the intensity of the radiation is sufficiently high, the redness usually becomes converted to a tan which can persist for a fairly long time and is termed pigmentation. If the radiation is not powerful enough, the redness disappears, for instance after about 20 to 40 hours, without leaving any visible trace. The most accurate erythema curve which has been evolved to date is that due to Coblentz and Stair [1]). In how far this erythema curve may be regarded as a standard applicable to all (normal) individuals is still a matter of controversy.

Some knowledge has also been gathered as regards the influence of wave length on a variety of other processes, but not sufficient for the data to furnish the requisite unit of dosage measurement. Thus it is known that pigmentation (tanning, see above) develops to some extent parallel to an erythema, although it has frequently been assumed that there are differences towards both the short and the long waves. Regarding the treatment of rickets which is based on the formation of vitamin D in the skin, it has been established that, just as in the production of an erythema, only wave lengths below approx. 0.31 μ are efficacious, although in other respects the curve is definitely different[2]). The bactericidal (bacteria-destroying) action is most powerful at approximately 0.25 to 0.26 μ and drops off in both directions. In the treatment of lupus (tuberculosis of the skin), the wave length interval between 0.32 and 0.35 μ appears to have the greatest activity. If the connective tissues of the eyes become inflamed by exposure to ultra-violet radiation, the eyes will ache after a few hours and will feel as if sand has entered them. Those who have ascended a glacier omitting to protect the eyes with a suitable pair of goggles will remember these symptoms. The protecting forehead affords a fairly satisfactory protection for the eyes against the solar rays incident from above, but the radiation reflected from snow, ice, still water surfaces and bright sand is incident on the eyes from a direction in which they are quite unprotected. This effect which is termed conjunctivitis (since is consists of an inflammation of the conjunctiva) soon disappears, for instance after the elapse of ten hours. The effect on the conjunctiva is still comparatively weak with rays of about 0.3 μ, but increases considerably in intensity with shorter waves. *Fig. 6* depicts, in addition to the erythema curve, also the conjunctivitis curve calculated from the data of Fischer, Eymers and Vermeulen [3]).

In view of the circumstances outlined above, the only satisfactory method for determining the dosage of ultra-violet radiation necessary in a specific case is to ascertain the physical composition of the radiation as accurately as possible, i.e. the intensity of the various wave lengths (in absolute

[1]) Res. Paper No. 631, Bur. Stand., J. Research, **12**, 13, 1934.

[2]) Cf. e.g. Bunker and Harris, Science, **83**, 487, 1936 E. Gorter, J. Pediatrics, **4**, 1, 1934.

[3]) Cf. the 1935 report of the Commission for ultra-violet rays of the International Illumination Committee.

units, e.g. ergs per sq. cm and sec) and to give the time of exposure. All other data, such as those expressed in "erythema units" — which one might be tempted to use owing to the ease with which they can be determined — provide no information

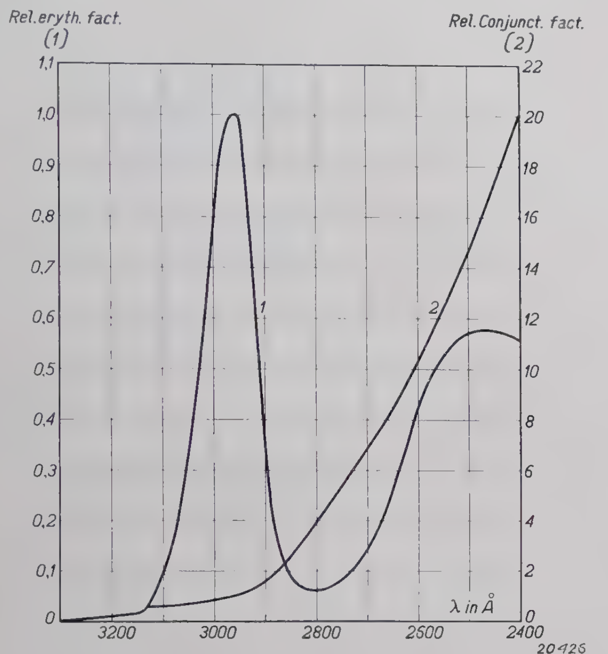


Fig. 6. *1)* Erythema curve of Coblentz and Stair.
2) Conjunctivitis curve of Fischer, Eymers and Vermeulen.

In both cases the reciprocal of the dosage required to obtain a just perceptible effect is plotted as a function of the wave length. The maximum values in the range of wave lengths shown have been arbitrarily put equal to unity.

of practical utility and are incomplete. The more knowledge is gained regarding the curves of biological action, the better equipped will be the investigator to calculate in advance the potential effect of a specific irradiation, i.e. as obtained with a radiation having a known spectral distribution curve.

The questions of principal current interest as regards dosage measurement and control with ultra-violet radiation are the following:

Determination of the spectral intensity distribution in the radiation from ultra-violet light sources and the plotting of the biological sensitivity curves [3]).

Spectral Intensity Measurements with the "Biosol"

The intensity of the spectral lines emitted by the "Biosol" between 3130 and 2480 Å was determined in absolute units. *Table I* gives the results of measurements for both types of "Biosol" without a filter or reflector. To permit comparison, the relative values obtained by Krefft and Pirani with a similar mercury discharge at a vapour pressure equal to that in the "Biosol" are also included.

Table I. Radiation Intensity of the "Biosol" at 50 cm distance.

Wave-length	Absolute intensity of "Biosol" A	Absolute intensity of "Biosol" B	Relative intensity (Kr. & P.)	Absolute : Relative A	Absolute : Relative B
Å	1000 ergs per sq. cm/sec.	1000 ergs per sq. cm/sec			
3130	2.01	4.76	66.4	30	72
3022	0.864	2.10	31.5	27	66.5
2967	0.493	1.05	14.8	33	71
2894	0.180	0.425	5.9	30^5	72
2804	0.325	0.855	11.3	29	75.5
2753	0.115	0.270	3.8	30	71
2699	0.150	0.350	4.9	30^5	71.5
2652	0.687	1.640	22.4	30^5	73
2537	1.17	2.370	29.1	40	81.5
2483	0.370	0.880	12.3	30	71.5
			Average	30	71.5

With the exception of the line with a wave length of 2537 Å, whose intensity in particular is closely dependent on the pressure, our values are in satisfactory agreement with the relative values of Krefft and Pirani. Since these investigators also made measurements at longer wave lengths, including those in the visible spectrum, we can calculate from their observations the intensity of the "Biosol" also in this range, using the above-mentioned conversion factor. As a check the intensity of the "Biosol" was calculated (on the basis of the relative ocular sensitivity curve and the value of the mechanical equivalent of light) from the intensity of the visible lines obtained in this way, and compared with the values obtained by direct measurement (Compare *Table II*).

Table II. Candle Power (Intern. Candles) of "Biosol" perpendicular to axis of tube.

Type	Calculated	Measured	Calc. : Measd.
"Biosol" A	675	625	1.08
"Biosol" B	1630	1570	1.04

Furthermore, by measuring the irradiation intensity with different wave lengths on a surface at a distance of 50 cm from the lamp both with and without the reflector, the intensification factor of the reflector was determined as a function of the wave length. *Table III* gives the results obtained for both types of "Biosol" with and without the filter.

Table III. Radiation Intensity of "Biosol" with reflector at 50 cm distance.

Wavelength	Intensity of "Biosol" A		Intensity of "Biosol" B	
	Without filter	With filter	Without filter	With filter
Å	1000 ergs per sq. cm/sec.	1000 ergs per sq. cm/sec.	1000 ergs per sq. cm/sec.	1000 ergs per sq. cm/sec.
5770/91	6.55	5.9	16.3	14.7
5461	5.9^5	5.35	14.7	13.2
4358	5.2	4.7	12.5	11.3
4078	0.48	0.43	1.15	1.04
4047	2.9	2.6	6.95	6.25
3655	9.4	8.45	22.4	20.2
3342	7.6	6.1	1.82	1.45
3130	5.75	3.8	13.6	9.0
3022	2.43	1.27	5.9	3.08
2967	1.35	0.59	2.85	1.25
2894	0.46	0.15	1.1	0.35
2804	0.82	0.15	2.15	0.41
2753	0.27	0.035	0.67	0.086
2699	0.35	0.028	0.84	0.067
2652	1.60	0.084	3.85	0.20
2537	2.55	0.032	5.15	0.064
2483	0.78	0.003	1.85	0.007
Illumination in lux	$7.85 \cdot 10^3$	$7.05 \cdot 10^3$	$1.97 \cdot 10^3$	$17.7 \cdot 10^3$

Erythema Action of the "Biosol" With and Without Filter

For each of the emitted lines the fractional contributions to erythema can now be calculated by multiplying the intensity by the erythema factor. *Table IV* gives the results of this calculation for "Biosol" B (with reflector, and at a distance of 50 cm) with and without the filter.

Summation gives a measure for the total erythema effect. It is found that with the "Biosol" B without filter the total effect is equivalent to that produced by a radiation exceeding 13 000 ergs per sq. cm and sec with a wave length of 2967 Å (at which, according to Coblentz and Stair, the erythema factor has its maximum value and is taken as equal to unity). The lamp with filter gives a radiation which as regards erythema effect is equivalent to that obtained with an intensity of 3560 ergs per sq. cm and sec at 2967 Å. It was ascertained experimentally that to obtain a specific erythema the time of irradiation required with the filter was three times that required without the filter. The agreement between calculation and direct measurement is thus satisfactory. According to Coblentz (IIe Congrès International de la Lumière, Copenhague, 1932) a just perceptible erythema on the inside of the forearm requires a radiation dosage of approximately 200 000 ergs per sq. cm at $\lambda = 2967$ Å. We found in good agreement with this figure that the limiting dose at a distance of 50 cm from the "Biosol" B with filter was about 45 secs with the majority of the individuals examined ($45 \times 3560 = 160\,000$). When using the lamp without a filter a weak erythema was observed in most cases after only 15 secs irradiation. However considerable differences existed between individual subjects.

As may be seen from Table IV, when using the "Biosol" without a filter about 45 per cent of the erythema is due to radiation with a wave length less than 0.280 μ, i.e. to a radiation which is not present in the solar spectrum. If the filter is fixed in front of the lamp, only a negligible proportion (about 3 per cent) of the erythema is due to this short-wave ultra-violet radiation. Corresponding differences naturally also apply to other biological processes. It is to this effect that the value of the filter is due, viz., that it adapts the action of the "Biosol" to make it comparable to that of sunlight.

Table IV. Intensity I, erythema factor f and erythema ratio I.f of "Biosol" B at 50 cm distance for different wave-lengths in absolute measure and as a percentage of the total erythema effect.

Wave-length	Erythema factor	Without filter			With filter		
		Intensity	Erythema ratio		Intensity	Erythema ratio	
Å		1000 ergs per sq. cm/sec	Abs.	%	1000 ergs per sq. cm/sec	Abs.	%
3130	0.03	13 6	408	3.1	9.00	270	7.6
3022	0.55	5.90	3240	24.6	3.08	1700	47.8
2967	1.00	2.85	2850	21.6	1.255	1255	35.2
(2925)	0.70	0.435	304	2.3	0.161	113	3.2
2894	0.25	1.10	275	2.1	0.352	88	2.5
2804	0.06	2.16	130	1.0	0.410	25	0.7
2753	0.07	0.67	47	0.4	0.086	6	0.2
2699	0.14	0.84	118	0.9	0.067	9	0.3
2652	0.25	3.84	960	7.3	0.201	50	1.4
(2576)	0.49	0.755	370	2.8	0.013	6	0.2
2537	0.55	5.16	2840	21.6	0.064	35	1.0
2483	0.57	1.85	1055	8.0	0.007	4	0.1
(2464)	0.57	0.27	154	1.2	—		
(2400)	0.56	0.74	415	3.2	—		
			13166	100.1		3561	100.2
Proportion of radiation with wave-lengths below 2800 Å in total erythema effect		45.4 per cent			3.2 per cent		

Conjunctivitis Effect of the "Biosol" B with and without Filter

With the aid of the curve for the conjunctivitis effect reproduced in fig. 6, the corresponding curve for the radiation of the "Biosol" B was determined

for an intensity equivalent as regards this effect, at the wave length 2967 Å *(Table V)*.

Table V. Intensity I, conjunctivitis factor c and conjunctivitis ratio I.c of "Biosol" B at 50 cm distance for different wavelengths.

Wave-length	Conjunctivitis factor	Without filter		With filter	
		Intensity	Conjunctivitis ratio	Intensity	Conjunctivitis ratio
Å		1000 ergs per sq. cm/sec,		1000 ergs per sq. cm/sec.	
3130	0.75	13.60	10	9.00	6.8
3022	0.85	5.90	5	3.08	2.6
2967	1.0	2.85	2.8	1.255	1.3
2925	1.5	0.435	0.6	0.161	0.2
2894	2	1.10	2.2	0.352	0.7
2804	4	2.16	8.6	0.410	1.6
2753	6	0.67	4.0	0.086	0.5
2699	7	0.84	6.3	0.067	0.5
2652	8	3.84	32.6	0.201	1.7
2576	10	0.755	7.5	0.013	0.1
2537	12	5.16	62	0.064	0.8
2483	15	1.85	27.8	0.007	0.1
2464	17	0.27	44.6	—	—
2400	20	0.74	14.8	—	—
			$188.8 \cdot 10^3$		$16.9 \cdot 10^3$

According to Fischer, Eymers and Vermeulen, the limiting dose at 2967 Å for conjunctivitis is approximately $12 \cdot 10^5$ ergs per sq. cm. This dosage can be obtained with approximately 7.5 secs irradiation with the "Biosol" B without filter (perhaps even a shorter exposure would be sufficient owing to the proportion of wave lengths below 0.240 μ which could not be taken into account). On the other hand, when using the filter on the lamp approximately 80 secs irradiation would be required to reach the limiting dosage. Experiments to determine this have not yet been made; but the results of calculation agree with general experience that between the lamps with and without the filter there is a marked difference as regards the conjunctivitis effect, which difference is much more pronounced than that found for erythema. The calculation given here is however very unreliable owing to the considerable uncertainty attaching to the conjunctivitis curve.

Treatment of Rickets

The requisite daily dosage found by Gorter and Soer [4]) for the treatment of rickets in children was as follows: $4.2 \cdot 10^6$ ergs (0.1 cal) on irradiation with a wave length of 2967 Å. This radiation was concentrated on a skin surface of 200 sq cm, i.e. $21 \cdot 10^3$ ergs per sq cm. In agreement with the dosage values given above for producing an erythema, no erythema results with this irradiation. Neglecting all consideration of other wave lengths, the requisite exposure to irradiation for the treatmant of rickets with the "Biosol" B with filter at a distance of 50 cm is found to be $21 \cdot 10^3 : 1255 =$ approximately 17 secs, if an area of 200 sq. cm is to be irradiated. On increasing the irradiated surface the requisite exposure time diminishes roughly in inverse proportion.

These examples will suffice to demonstrate how with an adequate knowledge of the spectral biological-activity curves the potential effects and the requisite irradiation times can be deduced from the known spectral distribution of the radiation from the "Biosol".

[4]) E. Gorter and J. J. Soer, Ned. T. Geneesk., **74**, 4310, 1930.

THE "PHILORA" SODIUM LAMP AND ITS IMPORTANCE TO PHOTOGRAPHY

by J. A. M. VAN LIEMPT.

Summary. In photographs taken with sodium light illumination the relative brightnesses of coloured objects are rendered very well. The reproduction becomes almost perfect if the sodium light is mixed with a suitable quantity of incandescent or mercury light. Furthermore sodium light offers unexpected advantages for the illumination of dark rooms.

Introduction

It may be stipulated as a requirement for non-coloured photographs that the colours naturally occurring in practically every group of persons or things photographed shall be reproduced in a greyish tint whose subjective brightness-impression is in agreement with the corresponding colours.

The old type of photographic plate, sensitive only to blue, did not meet this requirement at all. It was therefore an important step in the development of the photographic negative when H. Vogel discovered, in 1873, that by adding certain colouring matters to the photographic emulsion one could greatly increase the sensitivity of the emulsion to red and yellow rays. This gave rise to orthochromatic and panchromatic plates, now in general use. Meanwhile it has been found that although these plates considerably improved the photographic reproduction of colour, they have not yet proved capable of reproducing colours in an ideal manner when working with any of the artificial light-sources hitherto available in great variety. The only way to come to some extent near the desired result was to select, with a given light-source, a suitable filter for each class of plate.

As a matter of fact it is a laborious matter to select such a filter combination; besides, in such filters much light is lost by absorption, so that the required exposure time becomes longer than is desirable.

In collaboration with the court photographer F. Ziegler of The Hague we carried out several experiments on sodium lamps as a light-source for photography. The result, surprising though it first seemed, revealed the fact that this nearly monochromatic light-source solves the problem of photographic reproduction in a most satisfactory manner without making use of filters [1]).

By way of further illustration we are setting forth below a series of measurements carried out with various types of plates on the market with sodium light, which may be combined with other auxiliary light-sources.

For these measurements use was made of the Colour Test Chart (Stufenfarbentafel) [2]) issued by Agfa, a photographic reproduction of which is given in *fig. 1* (taken in daylight on panchromatic

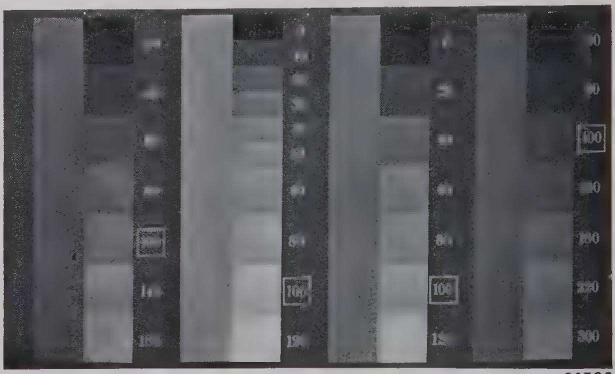


Fig. 1. Reproduction of the Agfa Colour Test Chart on panchromatic plate with daylight.

plates. This chart consists of 4 strips coloured red, yellow, green and blue respectively, each colour having beside it a numbered shade of grey. These four colours are the main colours of the spectrum and represent average colours as met with in practice (i.e. not pure colours of the spectrum).

As a result of scientific measurements in the Agfa laboratory it has now been definitely established that every colour, when correctly reproduced photographically, can be represented by a certain shade of grey which is indicated by the figure 100, which figure means that this particular shade of grey makes the same brightness-impression on our eye as the original colour.

A shade of grey that is indicated, for instance, by the figure 80 is one that reflects 80% white light compared with the shade of grey indicated as 100, and so on.

1) Several articles by F. Ziegler on this subject have appeared in „Bedrijfsphotographie" **17**, 247 1935); **18** 331 (1936).

2) See H. Arens and J. Eggert, Z. wiss. Phot. **27** 279 (1930) and M. Biltz, Wiss. Ver. Agfa **4**, 42 (1935).

If, therefore, a photograph is taken of the Colour Test Chart in the correct exposure time,using for illumination the light-source to be examined, we obtain a negative in which can be seen what shade of grey in the scale corresponds to the colour concerned.

If, for instance, red is reproduced by grey-shade 40, this means that the reproduction of red is too dark. In this case, therefore, the light-source used did not furnish sufficient red rays, or possibly the plate used was not sufficiently sensitive to red.

The correctness of the exposure time can easily be verified by the reproduction in the scale of grey. With correct exposure times all the stages of the scale of grey will be seen quite distinct from each other on the negative.

All the measurements were carried out with the following types of lamps:

1) "Philora" Sodium Lamp type SO 650, a 100 watt lamp with an efficiency of approx. 62 lm/watt [3]).
2) "Philora" mercury vapour lamp type HP 300, a 75-watt quartz lamp with an efficiency of approx. 36 lm/watt [3]).
3) "Philora" mercury vapour lamp type HO 1000, a 250-watt glass lamp with an efficiency of approx. 36 lm/watt [3]).

Along with these lamps some ordinary incandescent lamps are also used.

The spectrum of the sodium lamp is practically of a monochromatic yellow colour, in addition to which the lamp gives a little red neon radiation; the spectrum of the mercury lamps is a line spectrum in various colours, whilst the H.P. lamp emits a faint continuous spectrum as well.

The photographs were taken with the light of these lamps (or combinations thereof) on negative material as used in photographic practice. By way of comparison some photographs were also exposed in daylight in a room with a window facing northward, the sky being practically cloudless.

The results were as follows:

If, in the above *table I*, we first examine the photographs taken in daylight we find that the colour reproduction is far from perfect even when using good panchromatic plates. Moreover, mercury light is unsuitable, as it contains too much blue and too little red. Sodium light, on the other hand, gives the almost ideal colour reproduction in yellow and red — somewhat less good in blue — whereas the reproduction of green is comparatively poor with practically every kind of photographic material, because (for reasons we need not go into here) the negative material on the market is by its nature poorly sensitive to green.

Tabel I. Measurements in unmixed "Philora" light

Plate	Light-source	Colour reproduction			
		red	yellow	green	blue
Non-chromatic plates					
Gevaert Ultra Rapid	Sodium	100	100	50	60
	Daylight	30	10	25	180
Orthochromatic plates					
Gevaert Super Press	Sodium	90	110	50	60
	H.P.lamp	50	10	15	220
	H.O.lamp	40	20	25	190
	Daylight	30	20	30	180
Gevaert Ortho Process	Sodium	90	100	50	60
	Daylight	30	15	30	200
Panchromatic plates					
Gevaert Ultra Panchro	Sodium	120	120	50	40
	H.P.lamp	50	40	35	180
	H.O.lamp	45	40	35	160
	Daylight	60	40	40	140
Agfa Superpan	Sodium	140	120	60	40
	Daylight	90	40	30	140
Ilford Hypersensitive Panchromatic	Sodium	120	110	50	60
	H.P.lamp	55	30	30	180
	H.O.lamp	50	60	35	140
	Daylight	75	40	35	150

Furthermore, it is a noticeable fact that colour reproduction in sodium light is just as good on non-chromatic material as on orthochromatic material, so that — if the duration of the exposure is no object — negative material that is sensitive only to blue will do just as well as the more expensive panchromatic material; moreover, to a certain extent with orthochromatic material the the technique of development is simpler than with panchromatic.

We thus come to the remarkable paradox that it is possible to obtain good colour reproduction with the monochromatic light of sodium in conjunction with non-chromatic material.

From daylight photos we have already seen that the imperfect reproduction of colour obtained even with the most up-to-date panchromatic material, is due to the fact that this material is still insufficiently sensitive to red and yellow. Whilst the

[3]) In the determination of the efficiencies the losses in the series resistances and transformers are taken into account.

use of incandescent lamps as light-source does considerably improve the reproduction of red, that of yellow is still at a disadvantage. With sodium light, thanks to the large proportion of yellow it contains, the deficiency of yellow-sensitivity is entirely made good. As regards the reproduction of red it should be noted that the sodium lamp contains in the first place a small proportion of red neon rays. Moreover, the red occurring in practice is not a spectrally pure colour but contains, in the sense of Ostwald's colour theory, an appreciable proportion of white which reflects all other colours and especially the yellow adjacent to red. The ability of sodium light to give very fair, though not perfect, reproduction of blue, is also due to a white content in the blue colour met with in practice.

Since, further, the light reflected from sodium-lit objects of different colours is, unlike incandescent lamp light, nearly monochromatic, it is obvious that the same reproduction of colour will be produced on a nonchromatic as on a panchromatic plate. The exposure time will, however, be considerably longer for the non-chromatic plate on account of its low sensitivity to the yellow sodium line (0.59 μ). For sodium light photography it would indeed be sufficient to have a plate sensitive to yellow only, but this sensitivity to yellow should be as high as possible.

Measurements in mixed light

The reproduction of blue sodium light may be brought to perfection by adding the light of other light-sources to the sodium light. We merely state the final result.

On non-chromatic material, thanks to its high sensitivity to blue, a very slight admixture of incandescent lamp light proves sufficient.

Examples:

Emulsion: Gevaert Ultra Rapid (non-chromatic)
Light-source: Sodium lamp in conjunction with vacuum spiralised-filament lamp.

Light-source	Colour reproduction			
	red	yellow	green	blue
Sodium lamp	100	100	50	60
1w sodium lamp-power to 0.01w incand. light	100	100	50	100

In the case of orthochromatic plates which are not so sensitive to blue it is necessary to add somewhat more incandescent lamp light.

Emulsion: Gevaert Super Press (orthochromatic)
Light-source: Sodium lamp with vacuum spiralised-filament lamp.

Light-source	Colour reproduction			
	red	yellow	green	blue
sodium lamp	90	110	50	60
1 w sodium lamp-power to 0.30 w incandescent light	100	100	50	100

For panchromatic material — which is generally to be preferred on account of the shorter exposure time — the best results are obtainable with a combination of sodium and mercury light.

Emulsion: Ilford Hypersensitive Panchromatic
Light-source: Sodium light with HO mercury lamp.

Light-source	Colour reproduction			
	red	yellow	green	blue
Sodium lamp	120	110	50	60
1 w sodium lamp-power to 0.5 w mercury lamp-power	90	90	40	90

With these same light-sources we also found, in a similar manner:

Emulsion: Gevaert Ultra Panchro 8000 H and D
Light source: Sodiumlamp with HO mercury lamp

Light-source	Colour reproduction			
	red	yellow	green	blue
Sodium lamp	120	120	50	40
1 w sodium lamp-power to 0.5 w mercury lamp-power	120	100	50	80

Instead of adding mercury light we can also obtain good results by combining the sodium light with an "Argaphoto" lamp with blue filter.

The foregoing examples are merely intended as a guide to practical photographers, each of whom can, with the aid of Colour Test Charts, select for himself the right combination to use in conjunction with the negative material he prefers.

We would furthermore draw attention to the high efficiency of "Philora" lamps to which we referred at the commencement, this efficiency being such that, for the same current consumption, the lamps give two to three times as much light as ordinary incandescent lamps.

Another incidental advantage afforded by the sodium lamp when used for portrait photography is that, for a given illumination on the eye, the pupil is rendered larger by sodium light than by

Photo F. Ziegler, Den Haag

Photograph taken on the betrothal of H.R.H. Princess Juliana and H.S.H. Prince Bernhard.
The exposure was made by sodium light.

white light [4]) — a fact to which F. Ziegler has already drawn attention.

The accompanying photos *(fig. 2)* plainly indicate this. The same person has been photographed — in one instance after the eyes (while accomodated to infinate distance) had been exposed for 15 minutes to the light of a 300-lux "Argaphoto" lamp, and in another instance after such an exposure of the eyes to 300 lux of sodium light (luxmeter calibrated by means of the flicker photometer). In the first case the ratio $\frac{\text{iris diam.}}{\text{pupil diam.}}$ is 3.7, in the second case 2.0.

For the time of exposure in seconds the following formula may be used:

$$t = \frac{13500\, F^2}{L \times HD},$$

in which: F is the opening of the lens
L the illumination in lux on the place of the object to be photographed
HD the sensitivity of the plate for artificial light in Hurter and Driffield units.
This relation may be used for the mixed light for ortho- as well as panchromatic plates. Using pure sodium light it is valid only for panchromatic material.

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Fig. 2. Photo's taken after accomodation during 15 min. with 300 lux incandescent light (gasfilled) and with 300 lux sodium light respectively.

Illumination of the darkroom

Finally, we should like to draw the attention to an important application of the "Philora" Sodium Lamp, viz, as a dark-room lamp for use in handling gaslight papers when making prints and enlargements. Since the radiation of the sodium lamp is almost purely monochromatic and ordinary gaslight paper is insensitive to yellow, a photographer working by a 50-watt sodium lamp can flood his "dark" room with a sea of light — a boon formerly undreamed of! As, however, the electrodes of the lamp still give a faint continuous spectrum it is advisable that the lamp be fitted not only with an ordinary vacuum globe but also with an effective yellow filter whereby this white light is cut off and only a slight total loss of light occurs. Gevaert Ridax paper immersed in the developer can, for instance, be exposed for hours to this light without showing the slightest blur. However, when using bromide paper, which is more sensitive, greater caution is required and one cannot indiscriminately use this lamp.

The foregoing explanations will no doubt be sufficient to show the great advantages which are offered by sodium light both for photography and for cinematography. At the same time it furnishes us with a striking example of the manner in which a technical product devised for a different purpose may sometimes unexpectedly prove to be of far-reaching importance in allied branches of technique.

[4]) A similar effect is also obtainable with the "Photoflux" lamp. See Z. wiss. Phot. **33**, 287, 1935.

PRACTICAL APPLICATIONS OF X-RAYS FOR THE EXAMINATION OF MATERIALS IX

By W. G. BURGERS.

To decide whether in a particular case of the examination of a material the X-ray method might prove of use, it must always be remembered that this method gives in the first instance only information of the crystalline structure of a material. If a specific difference between two materials is due to a divergence in their crystalline texture, it may be assumed at least in principle that such difference can be detected by X-ray examination. In many instances the difference in texture is a result of differences in composition of the substances under consideration, and in a number of examples already cited, e.g. No. **9** (metallic deposition in the formation of metallic carbides), No. **10** (detection of thorium oxide and metallic thorium in a tungsten wire), and No. **15** (excessive tantalum content of tantalum carbide) it has been observed that the radiographs in cases of this type differ from each other in the relative positions or number of the interference lines.

Also in a material of homogeneous composition, differences in crystalline configuration can also occur, for instance as regards size and complete formation, or also the mutual orientation, of the crystals making up the material.

Differences of this type correspond in general to very pronounced differences in the physical and mechanical properties of the substance. Also in these cases, it may be expected that X-ray examination will give information of the characteristic state of the body. Some appropriate applications of the X-ray method in this direction have already been discussed in examples No. **3** (production of fissures in soapstone on firing) and No. **5** (texture of electrolytically-deposited nickel coatings), where it was found that the observed differences in properties were related to difference in the orientation of the crystals [1]). Attention should also be called to examples Nos. **17** and **19** where in a homogeneous substance differences in the conditions of internal stress were revealed by X-rays.

In the present and subsequent articles, a selection of further examples will be discussed in which different "states" of one and the same material can be differentiated by X-ray examination.

[1]) The difference between real and cultered pearls (example 4) is also due to this.

20. Recrystallisation of Drawn Tungsten Wire

An instructive example of the potential application of the X-ray method to the detection of changes in crystalline texture is obtained in the heat treatment of a machined metal. It is well known that plastic deformation of a metal causes the marked deformation of the original crystallites, a change which may be detected by the loss of definition in the crystals on etching the metal and the production of a more or less fibrous texture. If the deformed metal is maintained at a suitable high temperature for a sufficient time, recrystallisation will take place, in other words the fibrous texture will become reconverted to a normal crystalline texture made up of crystals with sharply-defined boundary planes. Recrystallisation takes place as a result of the displacement of atoms at specific highly-deformed and hence heavily stressed points in the machined metal, these atoms forming nuclei for new normal crystals which then grow at the expense of their distorted surroundings.

The etched figures reproduced in figs. 1*a* to *c* show this process in regard to a tungsten filament about 90 μ thick, using a magnification of over × 300. Pieces of this wire were subjected to heat treatment at an elevated temperature, and it is seen how as a result the original fibrous texture becomes altered: At the lowest reheating temperature employed (fig. 1*b*) there is little change to be seen; at the very most an incipient "coarsening" of the fibrous texture has developed. In the next stage illustrated (fig. 1*a*) this "coarsening" is more pronounced and the fibres are seen to disappear gradually; the formation of new crystallites however cannot yet be definitely deduced from the etched figure (the point marked with an arrow is probably the first beginning of this formation). In the section of the wire reheated to a still higher temperature (fig. 1*d*) this can already be distinctly observed: The fine striations at the top of the figure are due to a crystal which has become formed from a nucleus in this part of the wire and has already consumed part of the original fibrous texture. In the last figure (fig. *c*) recrystallisation has proceeded so far that the whole section of the wire has become occupied by a single crystal.

Figs. 1*f* to *k* reproduce the corresponding radio-

graphs of the wire sections [2]), and these also clearly reveal the changes which have taken place in the wire as a result of reheating. Fig. 1*f* and 1g both contain continuous lines, although the doublet, which is "sensitive" to a small alteration in the intra-atomic distance (for the explanation of this see article VIII of this series), is definitely separated in **g**, as compared to the original state in **f**, where it consists of a single ill-defined line. The latter is due to the fact that in the drawn wire the lattice

[2]) To obtain the radiographs a length of wire of about 1 mm was irradiated, i.e. about four to five times the length shown in the polished sections. The points in the radiographs are therefore due to a larger number of crystals than shown in the polished sections.

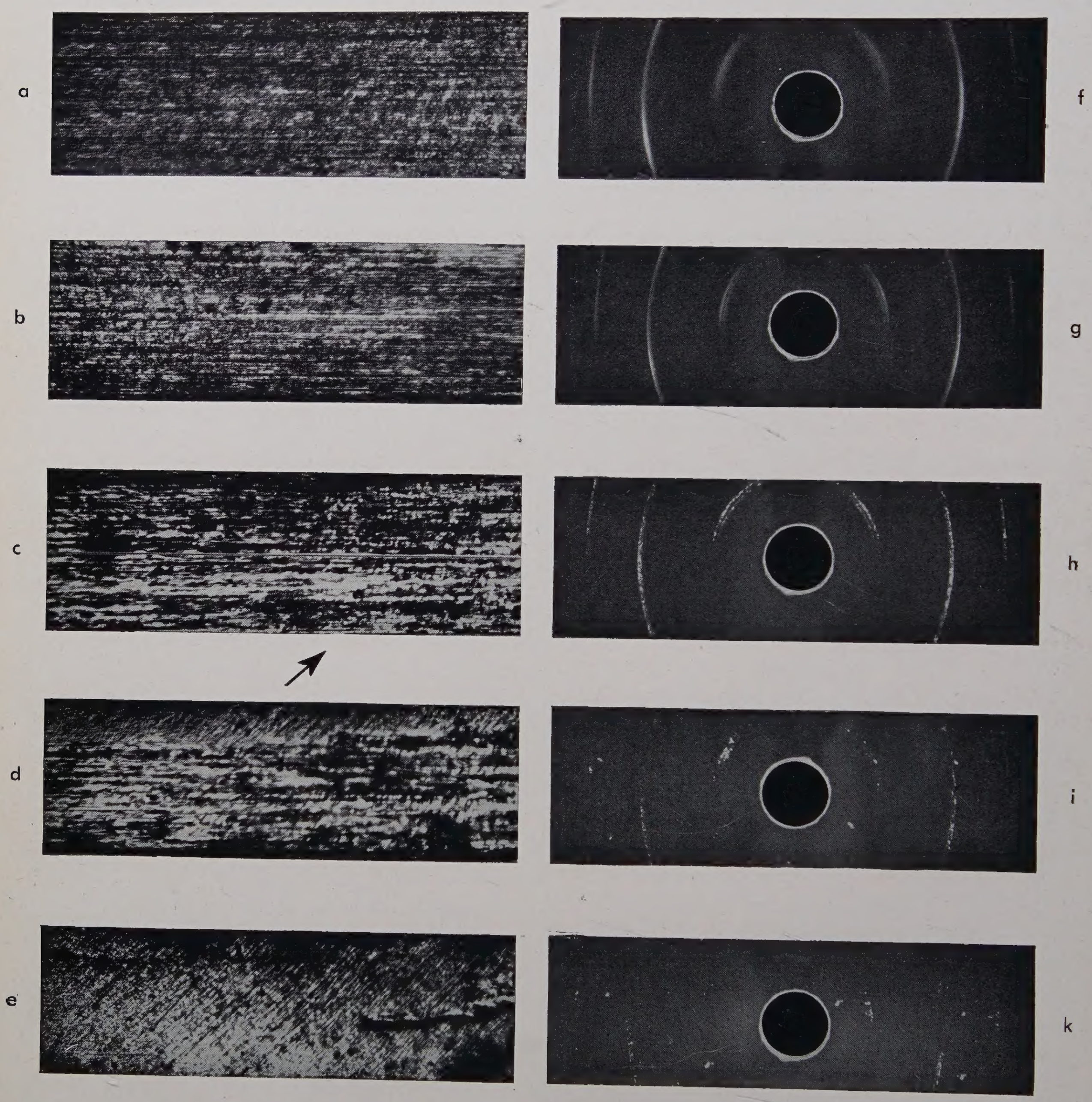

Fig. 1. Alteration in the crystalline texture of a drawn tungsten wire on heating to different temperatures in sequence.
a to *e*: Etched figures (magnification 325).
f to *k*: Radiographs.
The recrystallation taking place in the wire is indicated in the etched figures by the fibrous structure (figs. *a* and *b*) becoming converted to newly-formed crystals (fig. *d* above and fig. *e*) as revealed by fine parallel striations. In the radiographs recrystallisation is revealed by the initially continuous interference lines becoming resolved into separated spots. At the lowest reheating temperatures at which the fibrous structure is still practically unaltered (cf. fig. *a* with fig. *g*), the radiographs show a sharpened definition of the interference lines (cf. fig. *f* with fig. *g*) from which a diminution of the internal stresses may be concluded.

of the crystals has become somewhat distorted by the drawing process and thus gives rise to internal micro-stresses (see example **18** in article VIII). The first effect of comparatively small temperature rise is thus seen to consist of a decrease in these deformations of the lattice and hence of the internal stresses. Crystal growth susceptible to detection by X-rays has however not yet taken place. This is brought out by the fact that the lines in the radiograph have retained their continuous character.

In the piece of wire which was reheated to the next highest temperature (fig. 1*h*), the lines begin to be resolved into individual points. This phenomenon indicates that in the wire section irradiated by the X-rays crystals were already present of at least about 10μ in size, i.e. nuclear formation had been initiated, and the wire at least partially was in a state of incipient recrystallisation. With the progressive development of the recrystallisation process and the simultaneous disappearance of the original fibrous texture, the continuous character of the interference lines disappears completely (figs. 1*i* and 1*k*), and only a few spots remain which emanate from the relatively small number of newly-formed crystallites.

The value of radiographic examination in regard to polished sections is that each method of investigation supplements the other. While, for instance, in reheating the wire to the lowest temperature employed structural changes were not at all or barely observable in the polished sections (cf. *a* with *b*), the radiographs reveal (cf. *f* with *g*) that the stresses created by the drawing process have already diminished. Furthermore, it may be deduced from the definition of the interference spots in the radiographs of the crystallising wires that the freshly-formed crystals are to a large extent free from stresses, which also cannot be directly concluded from the polished sections. On the other hand the polished sections aptly bring out the shape and size of the crystals finally formed.

a

b

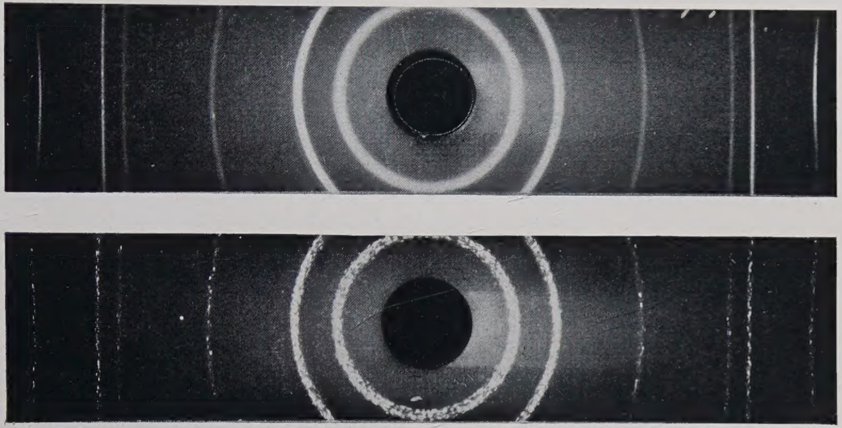

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Fig. 2. Occurrence of recrystallisation on heat treatment of nickel cathode tubes.
a: Radiograph of drawn tube.
b: Radiograph of recrystallised tube.

21. Nickel Tube for Oxide Cathodes

In indirectly-heated receiving valves with oxide cathodes, the oxide coating is deposited on short drawn nickel tubes which have been subjected to a special heat treatment, Recrystallisation may take place during their heat treatment, and is revealed in the radiograph, as in the previous example, by the continuous lines obtained with the drawn tube becoming resolved into individual spots.

On the examination by X-rays of two series of nickel tubes of different origin the difference was found that one series (cf. fig. 2*a*) has not yet recrystallised while in the other series recrystallisation has occurred (cf. fig. 2*b*). Moreover, from the density of the spots in radiographs of different recrystallised tubes certain conclusions could be drawn as regards the more or less advanced stage of the recrystallisation process.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1122: M. J. Druyvesteyn: Die Brennspannung eines Niedervoltbogens (Physica, **3**, 724 to 726, July, 1936).

The arc voltage of a low-voltage arc is measured as a function of the current intensity and the gas pressure, in the course of which distinct differences are observed between a tungsten and an oxide cathode. Partly these differences are probably due to differences in temperature of the gas just in front of the cathode, as a result of which, at the same gas pressure, the density in front of the oxide cathode is made much greater than in front of the tungsten cathode.

No. 1123: W. de Groot and J. H. Gisolf: De Geiger-Müller teller (Ned. T. Natuurk. **3,** 161-169, June, 1936).

This paper which was read before the Nederl. Natuurk. Ver. presents a survey of the literature dealing with the Geiger-Muller counter, followed by a report of observations made by the authors themselves on the discharge of the counter by means of a cathode ray oscillograph. The different forms of the wire potential as a function of the time which were found may be traced to the different values possessed by unavoidable capacities and resistances, as was illustrated by means of a substitutional circuit. It was shown in particular that the occasional instantaneous values of the wire potential, which are greater than to be expected from the corona characteristic, are in general not due to the potential between the electrodes falling below the "initial potential".

No. 1124: A. Bouwers and W. J. Oosterkamp: Die Unschärfe einer Röntgenaufnahme (Fortschr. Röntgenstr. **54,** 81-91, July, 1936).

The best definition is obtained in radiographs when the kinematic want-of-sharpness U_b, the screen want-of-sharpness U_f and the geometrical want-of-sharpness U_g are almost equal to each other, i.e. $U_b = U_f = U_g$. It is just as incorrect to use too short an exposure as to work with too small a focal point or with intensifying screens with an excessive high-definition.

No. 1125: E. J. W. Verwey and J. H. de Boer. Surface oxide films. (Rec. Trav. chim. Pays-Bas, **55,** 675-687, July, 1936).

The electrokinetic potential of rare metals and of carbon may be positive or negative according to the conditions ruling. The adsorption of oxygen at the surface of a pure metal imparts a positive potential to the latter with reference to the solution. In most cases the potential in the outermost part of the double layer is however of opposite sign, owing to the existence of a thin oxide film at the surface, i.e. a monatomic layer of oxygen which reacts chemically with the metal or the carbon, causing the production of a compound with a pronounced dipole moment. With carbon the activation energy for this reaction is so great that the surface oxide is formed only very slowly at room temperature, so that the carbon still has an electrokinetical positive charge. The nature of this activation energy and the manner in which the potential in the double layer varies are discussed in detail.

No. 1126: T. Jurriaanse and M. J. Druyvesteyn: The transition from a glow discharge to an arc discharge (Physica, **3,** 825-840, August, 1936).

The probability of the transition of a glow discharge to an arc discharge on contact between the cathode and a conductor is investigated. The probability of this transition is determined by a large number of factors, *inter alia* by the capacity and the potential difference between the conductor and the cathode; by the current density and the cathode fall in the glow discharge. Transition may occur equally on making or breaking contact between the conductor and the cathode. A determining factor in the probability of this transition to an arc is the energy of discharge between the conductor and the cathode.

No. 1127: K. F. Niessen: Zur Theorie der Brownschen Bewegung eines kritisch gedämpften Galvanometers (Physica **3,** 841-854, August, 1936).

A theoretical method is evolved for determining the Boltzmann constant k from the Brownian movement of a critically damped galvanometer. The method described differs fundamentally from the standard method in that the result is obtained from the time function of the mean value under measurement.